USAFETAC/TN-89/003

THE CARIBBEAN BASIN

A CLIMATOLOGICAL STUDY

by

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DECEMBER 1989

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13. Abstract: A climatological study of the Caribbean Basin, an area that includes Central America, the West Indies, and Northern South America. After describing the general geography of land areas in the Caribbean Basin, it discusses major meteorological features of the entire study area. The geography and major climatic controls of each of the three major regions that constitute the Basin are then discussed. Each major region is then broken into several sub-regions of "climatic commonality." Finally, the four so-called "seasons" in each of these sub-regions are discussed in considerable detail, with sections on "semipermanent climatic controls," "mesoscale and local effects," and "typical weather."

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PREFACE

This study was prepared by the United States Air Force Environmental Technical Application Center's Environmental Applications Branch, Readiness Support Section (USAFETAC/ECR), in response to a support assistance request (SAR) from the 5th Weather Wing, Langley AFB, VA, under the provisions of Air Weather Service regulation 105-18. It documents work done under USAFETAC project 703-32, and is the second in a series of such "descriptive climatologies " prepared at the specific request of operational users. The first product in this series was USAFETAC/TN-88/002, *The Persian Gulf Region--A Climatological Study*, published in May 1988. Like its predecessor for the Persian Gulf, this work is also complemented by two other Caribbean Basin studies: one describes transmittance climatology in the 8-12 micron band; the other, refractivity climatology. Publication of these complementary studies parallels or follows the parent work.

The project would not have been possible without the dedicated support of the many people and agencies we have listed below in the sincere hope we've not omitted anyone.

First, our deepest gratitude and appreciation to Mr Walter S. Burgmann, Mr Wayne E. McCollom, Mr Ronald W. Coyle, Mrs Kay Marshall, Mrs Marianne Cavanaugh, Mr Patrick Jones, Mr William Reller, Mrs Jeanette Davis, Mrs Glenda Armstrong, and Mrs Susan Keller of the Air Weather Service Technical Library. Without dedicated help from the staff of this superb atmospheric sciences library--arguably the best in the United States--this study would not have been possible.

Thanks also to Mr Mac Fountain, Mr Van Gibbs, Mrs Pam Hughes and other members of Operating Location A (OL-A), USAFETAC, Asheville, NC, for providing data and data summaries that the authors had previously thought impossible. These contributions were also vital.

To Maj William F. Sjoberg, SMSgt Charles Travers (USAF-Retired), TSgt Morris Friedman, and SSgt Gordon Hepburn of USAFETAC's Readiness Support Section (ECR), our thanks for their hard work, assistance, advice, and encouragement. When big problems came up, at least one of them was able to provide a solution.

Thanks to Mr Robert Fett and Mr Ron Picard of the United States Naval Environmental Prediction Research Facility for lending us large parts of their archived meteorological satellite imagery and analyzed chart archives. This information provided many insights into specific meteorological situations that were not available from other sources. Their permission to reprint selected images is gratefully acknowledged.

Thanks to Mr Maurice Crewe of the United Kingdom Meteorological Office for providing copies of studies not available elsewhere.

Thanks to Lt Col Kenneth Hertzler, Maj Douglas Pearson, Capt Michael Condray, Capt Eugene Dobry, CMSgt Virgil Killman, MSgt Thomas Gilligan, MSgt Charles Lau, and SSgt Dale Llewellyn (all United States Air Force) and Professor Forrest Williams, United States Naval Postgraduate School, for "peer reviews" of draft manuscripts.

The senior author also thanks those many United States, Central American, and South American meteorologists with whom he had the pleasure of discussing the meteorology and climatology of the study region during the past 8 years. This study would have been much the worse off without their contributions.

Finally, all the authors owe sincere gratitude to the Technical Editing Section of the AWS Technical Library. Special thanks to Sgt Corinne Gage for her superb technical illustrating skills; without her patience and cooperation, many of the illustrations included here would not have been possible. Profound and heartfelt thanks go from all the authors to the AWS Technical Editor, Mr George M. Horn. Without his writing and editing skills, complemented by 35 years of weather and aviation experience, this work would have been far poorer and less intelligible. He thwarted our best efforts to confuse readers by organizing our thoughts and turning them into plain language.

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INTRODUCTION

AREA OF INTEREST. This study describes the climatology and meteorology of the Caribbean Basin. As treated in this study, that region includes Central America, the West Indies, and northern South America south to the Amazon River. Figure 1-1, next page, shows the complete area of interest and its three major subregions:

Central America extends from the Isthmus of Tehuantepec southward to the Colombian frontier and the waters immediately offshore.

The West Indies includes all the West Indian islands and the waters of the Caribbean Sea.

Northern South America includes the entire northern portion of the continent from the Caribbean south to a line along the Amazon River-Rio Maranon system from Belem, Brazil, to 5° S on the Pacific coast. Immediately adjacent offshore waters are included.

Each of these three sub-regions has been further divided into zones of "climatic commonality." Central America has been split into *seven* such zones, the West Indies, *four*, and northern South America, *nine*. These zones are shown on maps in Chapters 3 through 5.

STUDY CONTENT. Chapter 2 provides a general discussion of the major meteorological controls that affect the Caribbean Basin. These range from the *macroscale* ("semipermanent climatic controls"), through the *synoptic* ("tropical disturbances"), and all the way to the *mesoscale* ("land-sea breezes"). The individual treatments of each climatic zone in subsequent chapters do not include repeated descriptions of these phenomena, but they do provide specifics unique to the individual region or zone in question. Therefore, meteorologists using this study should read and consider the general discussion in Chapter 2 before trying to understand or apply the individual climatic zone discussions in Chapters 3 through 5. This is particularly important because the study was designed with two purposes in mind: first, as a master reference to the entire Caribbean Basin, and second, as a modular reference to the several sub-regions of the Caribbean Basin.

Chapters 3 through 5, then, amplify the *general* discussions in Chapter 2 by describing the geography, climate, and meteorology of the Caribbean Basin's three individual sub-regions (Central America, the West Indies, and Northern South America). There are detailed discussions of each of the three subregions' "climatic zones of commonality," or regions that are known to feature reasonably homogeneous climatology and meteorology. (Note: In mountainous areas (such as the Northern and Southern Mountains of Central America and the Andes of northern South America), meteorology is not necessarily *internally* homogeneous, but it is distinctly different from that of the areas immediately adjacent.

Discussions of each "season" in each climatic zone are organized in the following order:

Semipermanent Climatic Controls
Transitory Synoptic Features
Mesoscale and Local Effects
Typical Weather
General sensible weather:
- *Sky cover*
- *Wind*
- *Thunderstorms*
- *Precipitation*
- *Temperature*

CLIMATOLOGICAL REGIMES. Since our entire study region lies in the tropics, discussions are directed to phenomena that are common to the tropics: that is, the Monsoon Trough (or Intertropical Convergence Zone/ITCZ), trade winds, tropical disturbances, and so on. All three study regions, however, are affected by polar surges during their respective hemispheres' temperate zone winters. In the northern hemisphere, these surges routinely reach southward to the central Caribbean Sea and Honduras; in the southern hemisphere, antarctic surges reach northward to the Amazon River. Surges in either hemisphere can, in extreme cases, penetrate all the way to the Caribbean coast of South America. The main effect of these outbreaks is to enhance convection along and ahead of surge lines and almost totally supress it behind them.

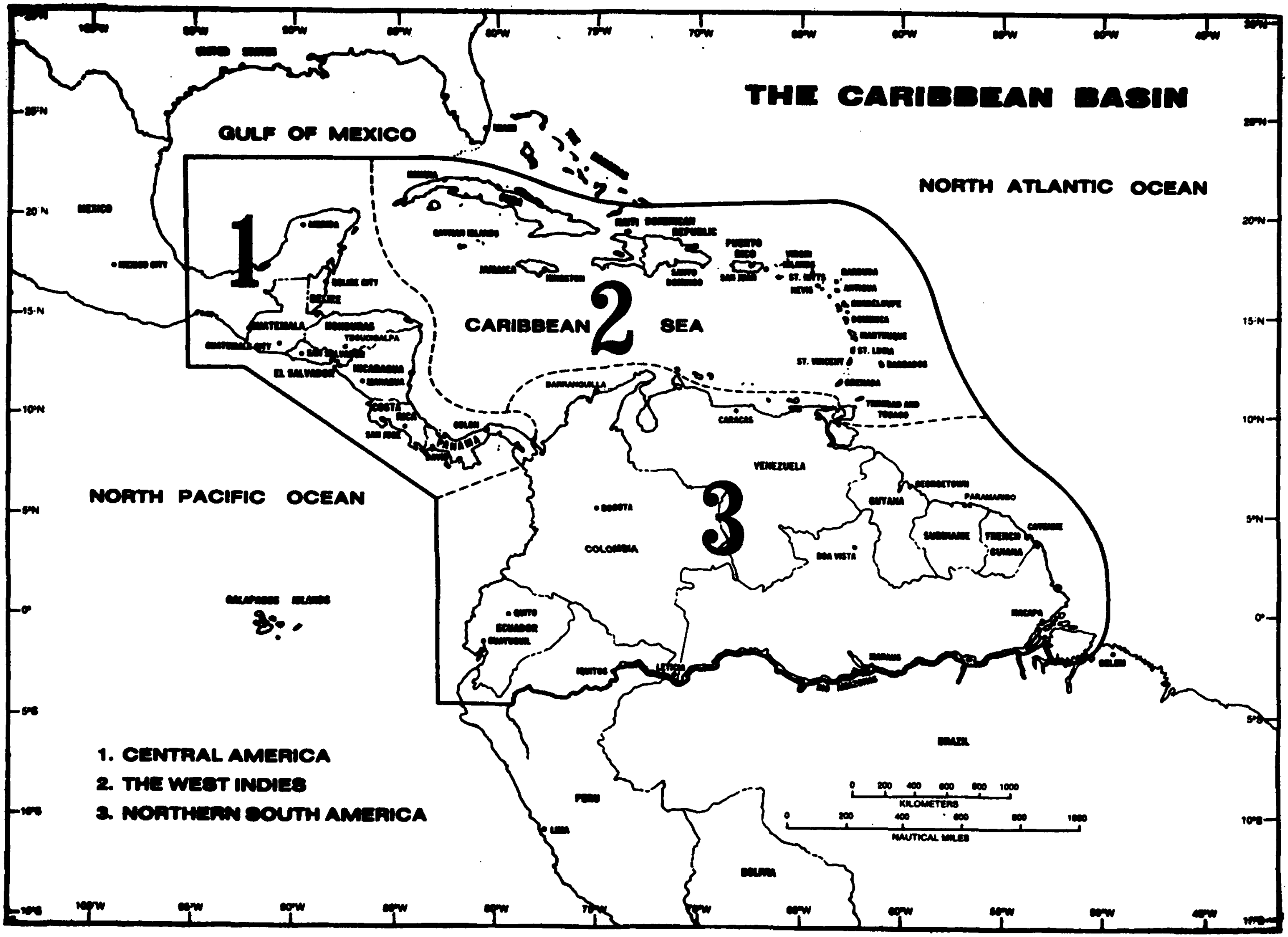


Figure 1-1. The Caribbean Basin and its Three Subregions.

The traditional "four seasons," at least as far as temperate zone meteorologists know them, are absent in the Caribbean Basin. Instead, tropical meteorologists recognize only a "wet season" and a "dry season," with periods of transition from one to the other. We have used these tropical expressions of "season" throughout this study, even though the terms "wet" and "dry" can become blurred in certain areas--notably on the Pacific coast of Colombia and in the extreme western portion of the Northern Amazon Basin.

CONVENTIONS. The spellings of place names and geographical features are those used by the United States Defense Mapping Aerospace Center (DMAAC). Distances are in nautical miles, except for visibilities, which are in statute miles. Elevations are in feet with a meter or kilometer value immediately following. Temperatures are in degrees Fahrenheit with a Celsius conversion (°C) following. Wind speeds are in knots. Precipitation amounts are in inches, with a millimeter (mm) conversion following.

DATA SOURCES. Most of the information used in preparing this study came from two sources, both within the United States Air Force Environmental Technical Applications Center (USAFETAC). Studies, books, atlases, and so on were supplied, with rare exceptions, by the Air Weather Service Technical Library, or AWSTL, which is the only dedicated atmospheric sciences library in the Department of Defense and the largest such library in the United States. Climatological data came direct from the Air Weather Service Climatic Database or through Operating Location A, USAFETAC--the branch of USAFETAC responsible for maintaining and managing this database.

RELATED REFERENCES. This study, while more than ordinarily comprehensive, is certainly not the only source of meteorological and climatological information for the military meteorologist concerned with the Caribbean Basin. The United States Navy has either published or is preparing to publish several excellent Naval Tactical Applications Handbooks for the Caribbean Basin. For example, Naval Environmental Prediction Research Facility (NEPRF) Technical Report 89-08, *Forecasters Handbook for Central America and Adjacent Waters*, September 1989, is an excellent guide for specific Central American forecasting techniques. Certain USAFETAC Data Summaries provide summarized meteorological observational data for many major airports in the Caribbean Basin. Staff weather officers and forecasters are urged to contact the Air Weather Service Technical Library for as much data on the region as is currently available.

Chapter 2

MAJOR METEOROLOGICAL FEATURES OF THE CARIBBEAN BASIN

The "major meteorological features" of the Caribbean Basin are listed below as they appear and are described in this chapter. These features affect the weather and climate of the Caribbean Basin the year around. The same features are discussed more specifically in subsequent chapters as they relate to individual regions and subregions of the study area.

THE MONSOON TROUGH (or Intertropical Convergence Zone--ITCZ). The Monsoon Trough marks convergence between the air of the northern and southern hemispheres. Here, the northeasterly trade winds that originate as air flowing around the North Atlantic High meet southeasterly trade winds that originate as air flowing around the South Pacific and South Atlantic highs. Flow from the South Pacific high routinely crosses the equator and recurves eastward. In such cases, the recurved air is called the "equatorial southwesterlies" or "equatorial westerlies." Northward penetration of this air depends on the time of year and the location of the South Pacific High. Because of the converging flow, the Monsoon Trough is the zone of maximum cloudiness and rainfall. Precipitation and cloud clusters in Central America north of the mean Monsoon Trough are normally concentrated along the continental divide and onshore from each coast, the products of orographic lift and/or land/sea breezes. In some high summer cases, the Monsoon Trough actually oscillates between onshore and offshore, a result of diurnal heating. Convection and associated precipitation is concentrated within discrete cloud clusters or bands scattered along the Trough. (See "tropical disturbances" for further discussion of these cloud clusters and what causes them.) The solid look of the Monsoon Trough on satellite imagery results fromthe merger and advection of cirrus "blowoff" from these convective clusters.

Pressures in the Monsoon Trough are below 1010 millibars. The Trough oscillates north and south in response to the sun's position and to cross-equatorial surges. These surges--trade wind or ex-polar frontal--may drive the Trough well poleward of normal high-sun positions. (For oceanic or flat terrain air flow, the distance poleward that a cross-equatorial surge may push the Trough depends on the angle at which the flow crosses the equator. Except during the late northern hemisphere summer, the Monsoon Trough is normally discontinuous across the Andean ranges. Under these conditions, the eastern Pacific Monsoon Trough moves independently of the South American/Equatorial Atlantic portion. From December through February, the Monsoon Trough (in both oceans) and the South American continental surface low-pressure cell are located at their southernmost positions--see Figure 2-1.

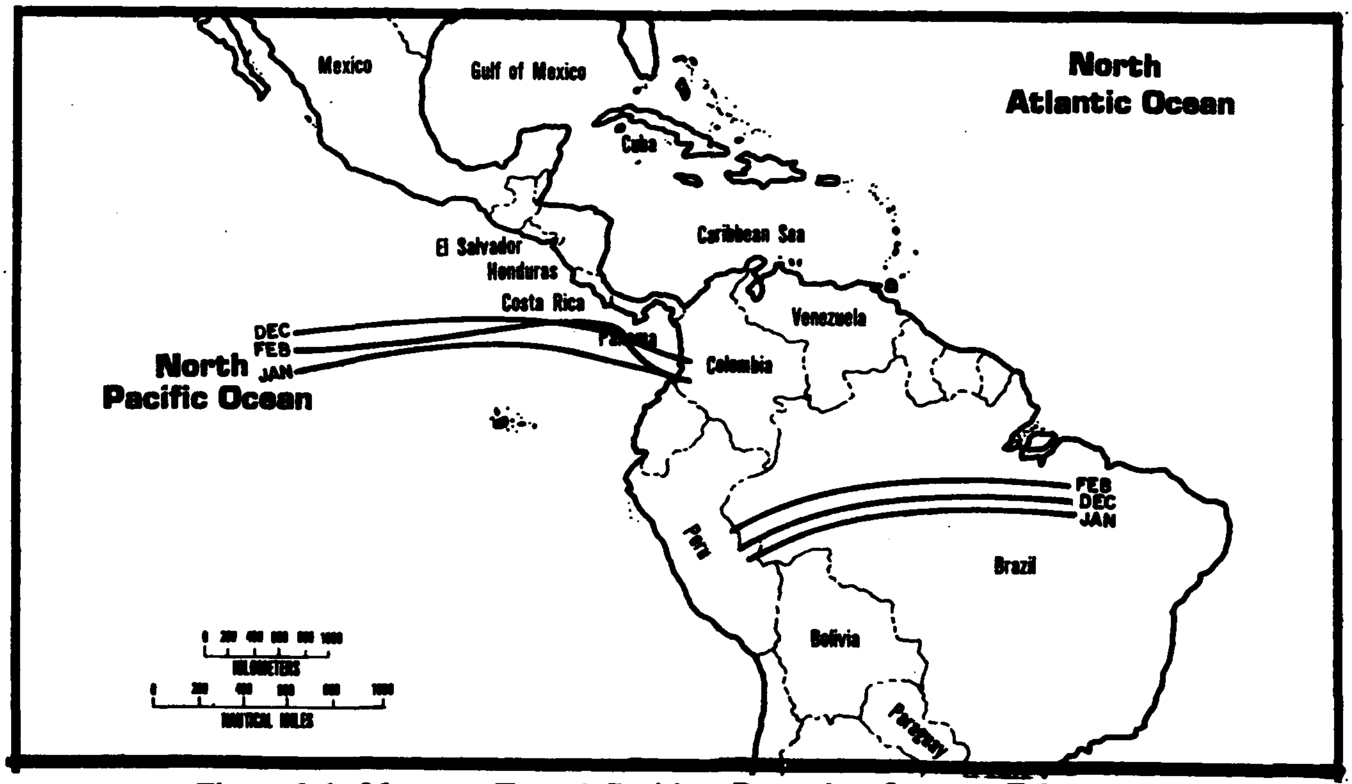


Figure 2-1. Monsoon Trough Position, December-January-February.

The northeast trade wind regime is intensified by prevailing anticyclonic circulation at 500 millibars over Central America. (This anticyclonic flow is only intermittently interrupted by deep extra-tropical westerly troughs penetrating into the tropics; see "Semipermanent Climatic Controls--Upper Levels" for further discussion of these troughs.) The northeast trades extend equatorward to roughly 5° N in the Eastern Pacific. Pacific cross-equatorial flow (from the southern hemisphere) is confined to the area between the equator and 5° N; this flow originates on the northeastern side of the South Pacific high. Low-level flow across the equator is weakest during northern hemisphere winter due to displacement of the South Pacific high poleward. As a result, the Pacific low-pressure trough forms between 2 and 5° N. The Andean ranges, with mean heights of 4 to 5 kilometers, normally prevent the trough from continuing eastward. Instead, it is found again along the eastern slopes of the Andes in southeastern Peru near 10° S. It lies along a west-southwest to east-northeast line to just south of the mouth of the Amazon. Here it enters the equatorial Atlantic and continues eastward along 2-4° N. Brazilian (and some American) meteorologists believe that trade wind surges (see "tropical disturbances" under "Transitory Synoptic Features") along the north side of the trough recurve as cross-equatorial flow. Becoming northwesterlies, they eventually (according to this theory) drive the Monsoon Trough deep into the south-central Brazilian highlands during March and April.

In March through May, the northward movement of the sun combines with the return of strong cross-equatorial flow from the northward-moving South Pacific High to force the Monsoon Trough northward (see Figure 2-2). Similarly, increasing southern hemisphere polar outbreaks combine with the northward march of the sun to move the South American portion of the Monsoon Trough north in the central Amazon basin. At the same time, the equatorial Atlantic Monsoon Trough position shifts northward, leaving the Brazilian coast towards the northeast, near 5° N.

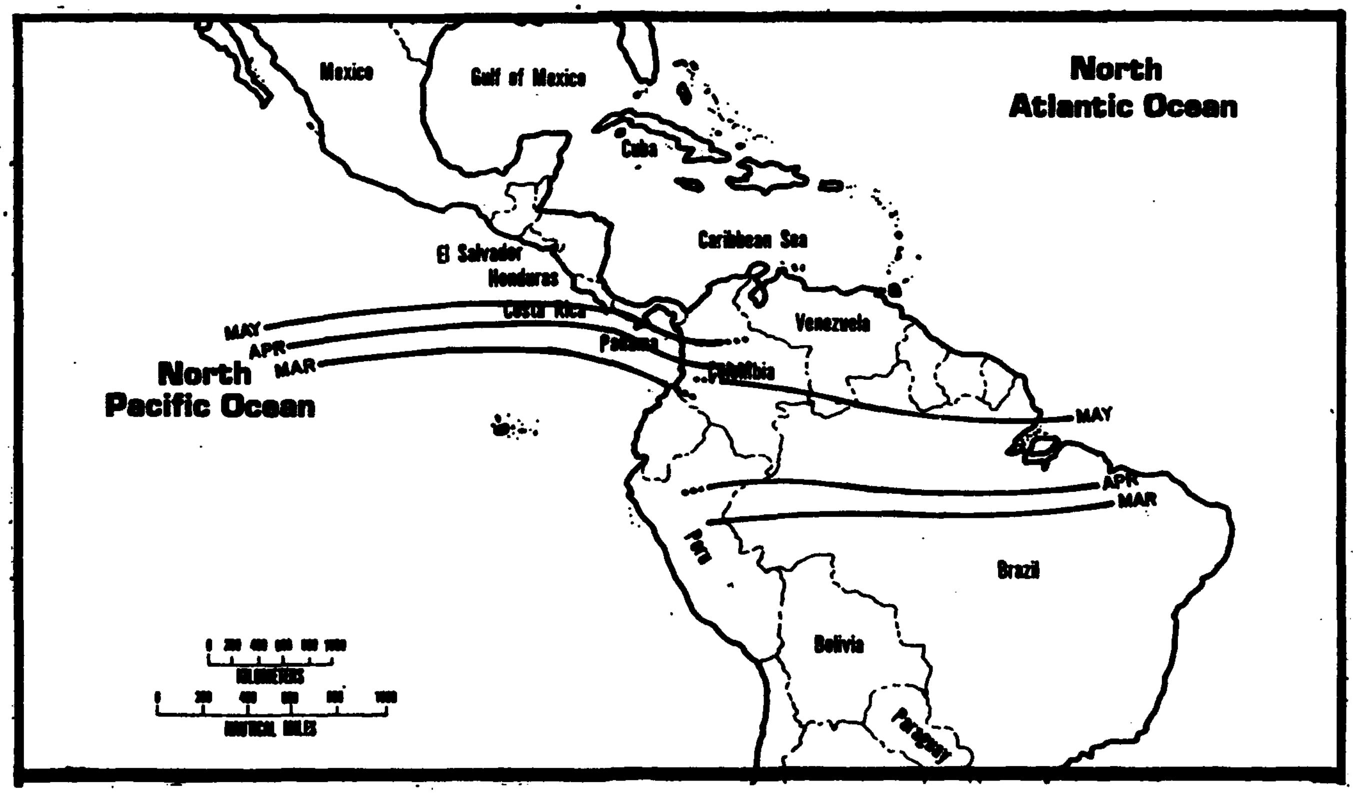


Figure 2-2. Monsoon Trough Position, March-April-May.

There is no permanent anticyclone in the equatorial eastern Pacific north of the equator during June, July, and August; the Eastern Pacific High is too far northwest to directly affect the study area. Cross-equatorial flow from the South Pacific High (the "equatorial westerlies") acts, in effect, as the high pressure cell. See Figure 2-3.

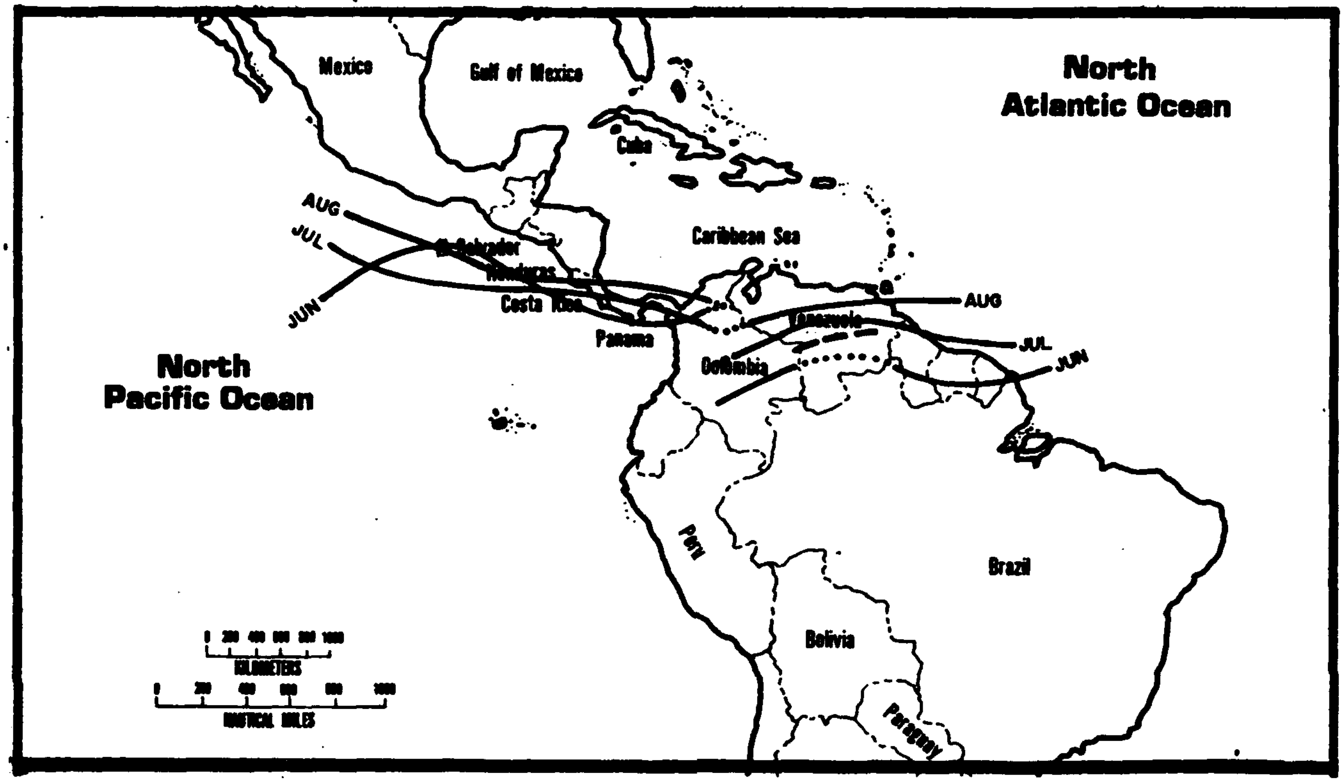


Figure 2-3. Monsoon Trough Position, June-July-August.

The mean position of the trough parallels the Pacific coast of Central America, and reaches its most northward points in late May or early June. During July, it retreats southward. This "surge and retreat" pattern is apparently in response to the westward and northward extension of the North Atlantic High over the Caribbean during June and early July. Once established off the Pacific coast of Central America in June, the Monsoon Trough is anchored by three cyclonic centers: one offshore of southern Mexico, one off Nicaragua, and another in the Gulf of Panama. From here, the Trough normally surges back and forth across the Isthmus of Panama in response to southern hemisphere cross-equatorial surges and northern hemisphere trade wind surges (which see). Due to terrain effects, the Trough may or may not be found across northern Colombia, but it is not normally apparent as a distinct trough west of the eastern Colombian plains. Terrain along the Caribbean coast of South America (notably the eastern spur of the Andes in Venezuela) combined with cold water immediately offshore of Venezuela normally inhibits northward movement of the Trough into the Caribbean itself. By August, the Trough follows the Orinoco Valley, entering the Atlantic at the mouth of the Orinoco and trending east-northeastward. In the equatorial Atlantic west of 35° W, the large North Atlantic High maintains northern hemisphere trade wind circulation consistently to 10° N. Similarly, the South Atlantic (or St Helena) High maintains southeasterly trades over the South Atlantic northward to near 10° N for those portions of the South Atlantic west of 35° W. Pacific cross-equatorial flow strengthens in September and drives the Monsoon Trough to its northernmost position. But the flow weakens in late fall as the South Pacific High moves southwestward and the eastern Pacific Monsoon Trough retreats southward--see Figure 2-4.

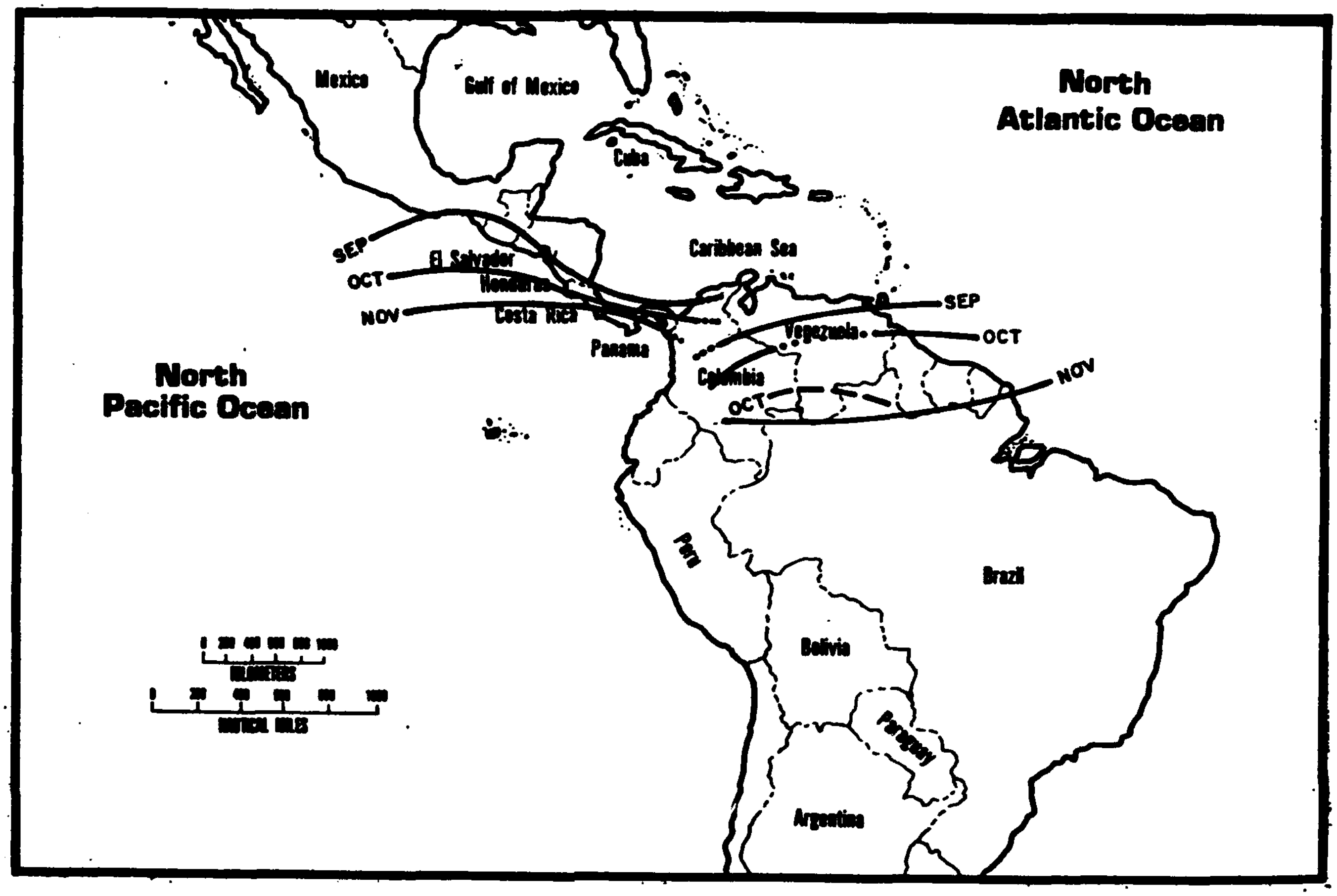


Figure 2-4. Monsoon Trough Position, September-October-November.

A combination of (1) weaker Southern Hemisphere flow, (2) the onset of Northern Hemisphere polar surges over Central America and the Caribbean, and (3) the southward movement of the sun drives the Monsoon Trough southward into the interior of South America. At the same time, the Equatorial Atlantic Monsoon Trough moves southward, to near Belem, in response to the solar cycle and associated southward movement of the North and South Atlantic Highs. September and October may see the extreme northern position of the Monsoon Trough in response to strong equatorial southwesterlies in the eastern Pacific, Panama, Costa Rica and western Nicaragua. In extreme cases (as shown in Figure 2-5), these southwesterlies drive the Monsoon Trough far enough north to cross Central America in Guatemala, enter the Caribbean just north of Honduras, slant east-southeastward to cross the Lesser Antilles between Trinidad and Barbados, and finally move eastward into the Atlantic near 15° N. Such extreme northerly positions, however, are rare.

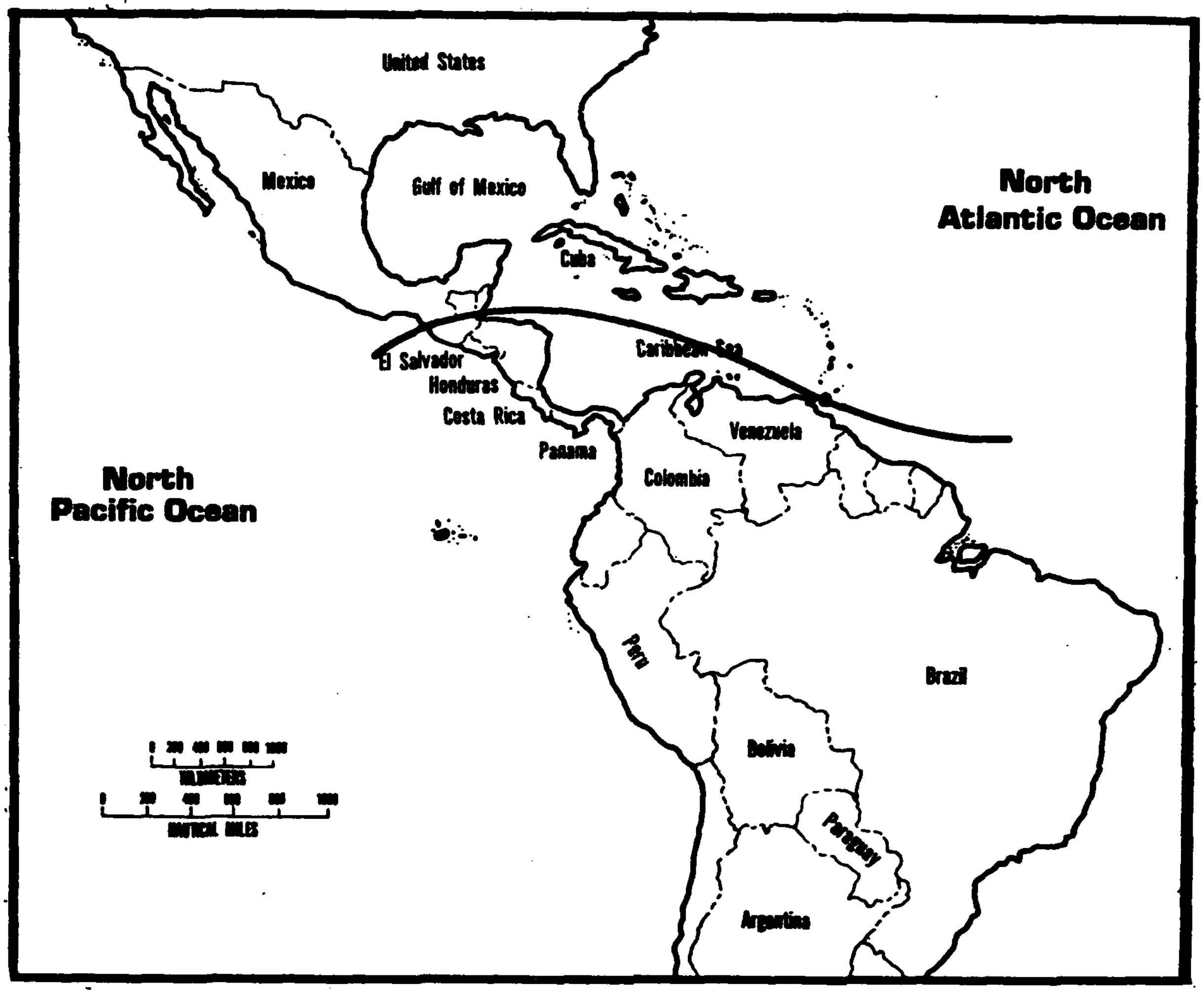
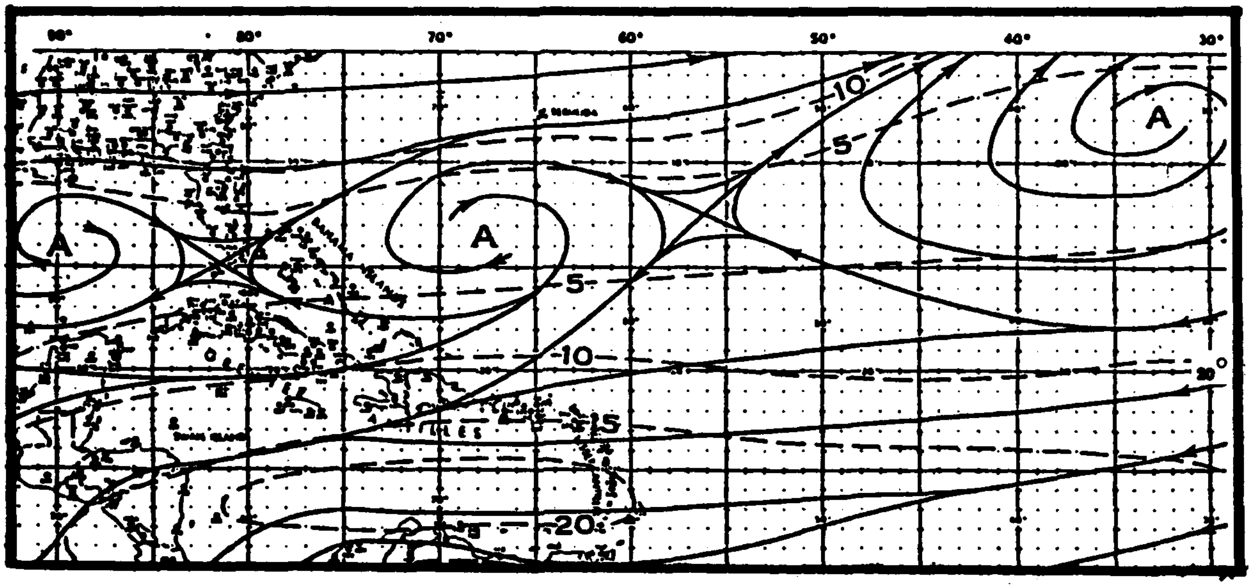


Figure 2-5. Extreme Northernmost Position of the Monsoon Trough.

NORTH ATLANTIC ("AZORES") HIGH. This semipermanent high pressure cell represents the descending edge of the northern hemisphere Hadley cell. Extending west to east from North America to Africa, this high pressure center is normally centered near 30° N, 35° W in winter and near 35° N, 40° W in summer. It covers most of the southern North Atlantic Ocean. In winter, east-northeasterly trades winds around its southern periphery move over the Caribbean Basin at 9 to 12 knots. When the cell shifts northward in summer, the trades become east-southeasterly at 7 to 10 knots. This circulation is persistent below 12,000 feet (3,660 meters) MSL. During the northern hemisphere summer, the depth of the northeasterlies increases as latitude decreases. Over the central Caribbean they reach 20,000 feet (6.1 kilometers); over the Orinoco Basin, they extend to 40,000 feet (12.2 kilometers). The southern side of the tradewind circulation converges with the South Atlantic High cross-equatorial flow over the equatorial Atlantic and in the Monsoon Trough, which see. Figures 2-6a & 2-6b show mean gradient flow over the North Atlantic for January & April and for July & October.



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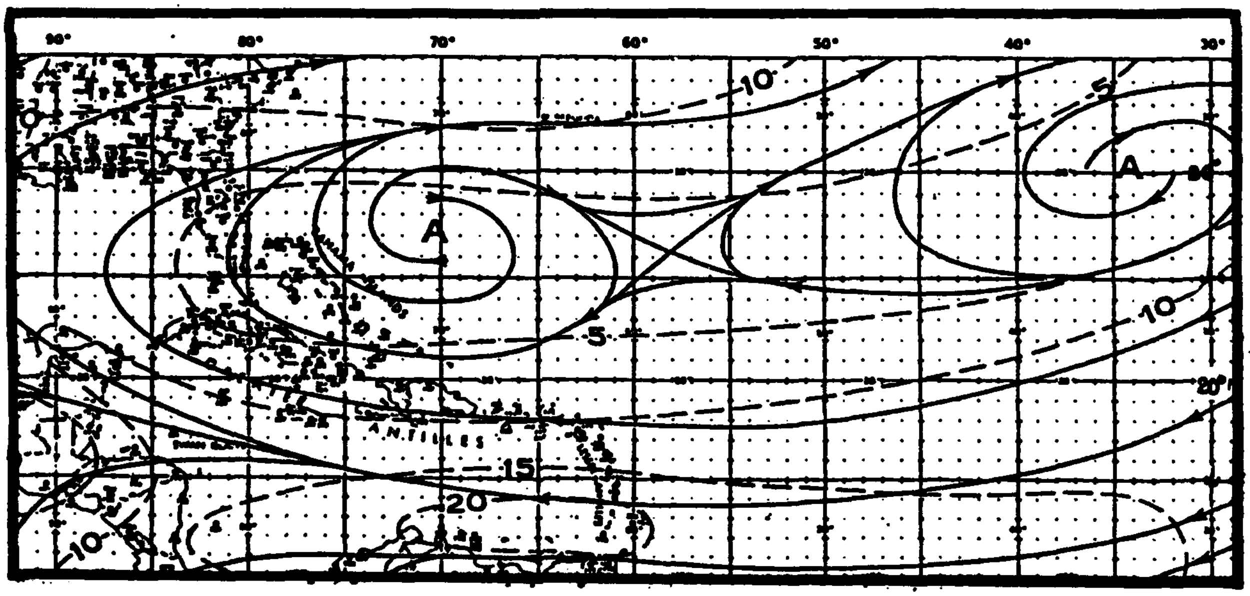

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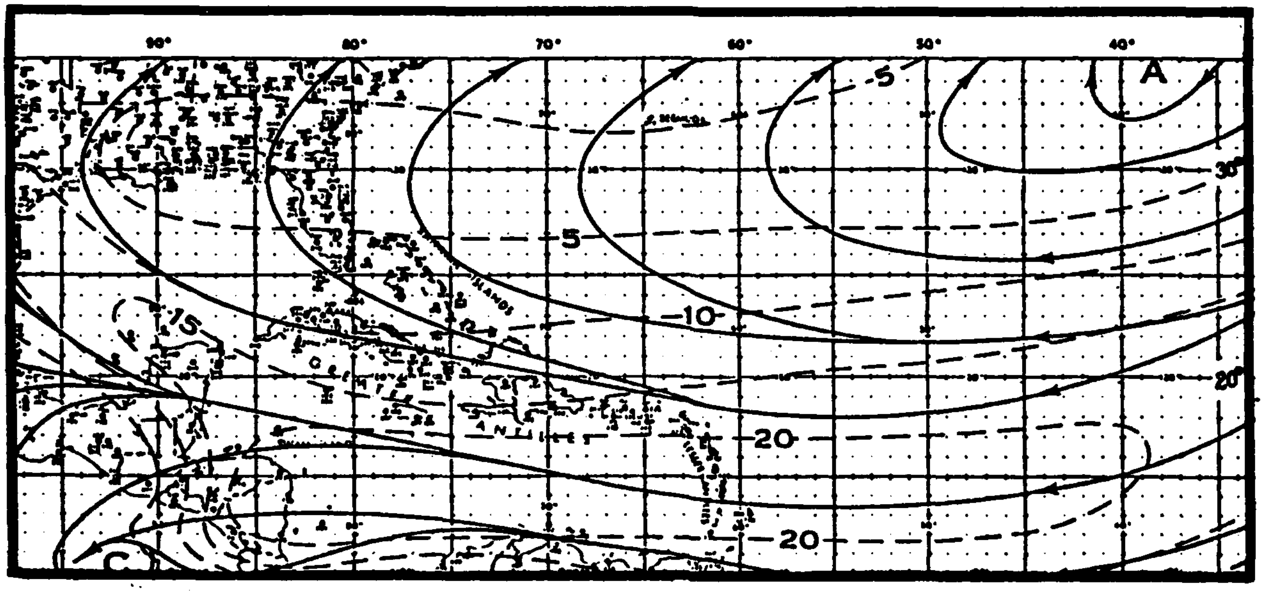
Figure 2-6a. Mean Gradient Flow, North Atlantic, January & April.



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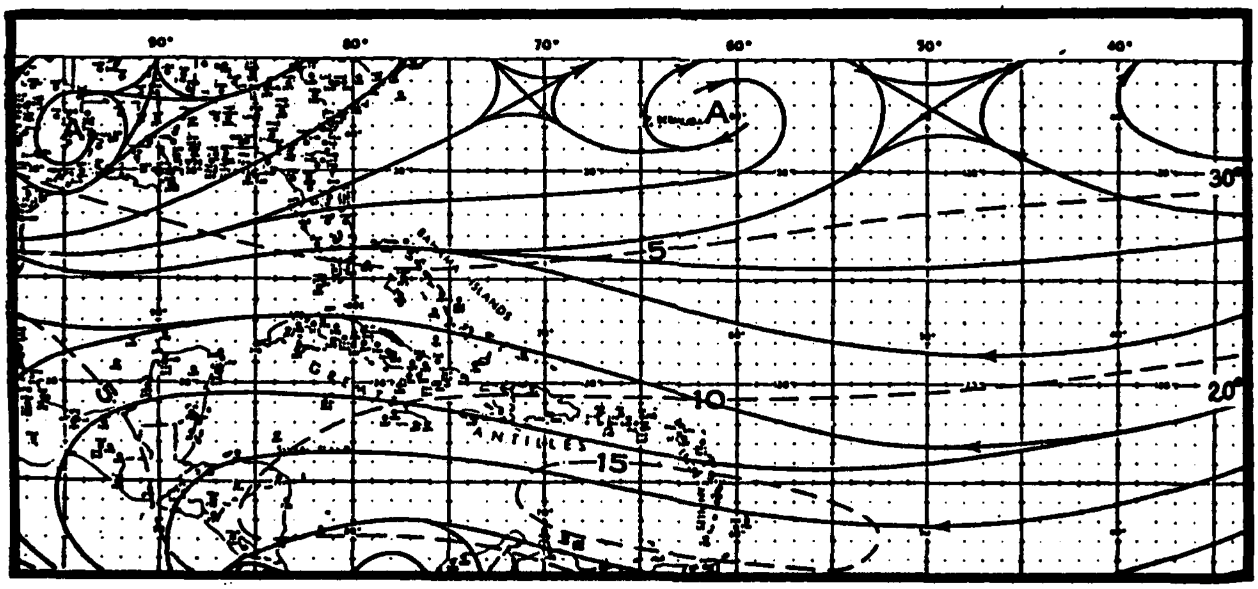

OCTOBER

Figure 2-6b. Mean Gradient Flow, North Atlantic, July & October.

Figure 2-7 shows mean mid-level flow for January, April, July, and October. At 500 millibars, the high pressure cell slopes southwestward with altitude from its surface position. During northern hemisphere winter, it covers the Caribbean Sea. In summer, it shifts northward into the Gulf of Mexico, the southern United States, and the north Atlantic Ocean. Although this shift allows a deep easterly flow over the entire Caribbean Basin during northern hemisphere summer, these configurations tend to break down during late northern hemisphere fall and spring. These are *mean* positions; in northern hemisphere winters, troughs *in* the mid-latitude westerlies often penetrate deep into the tropics.

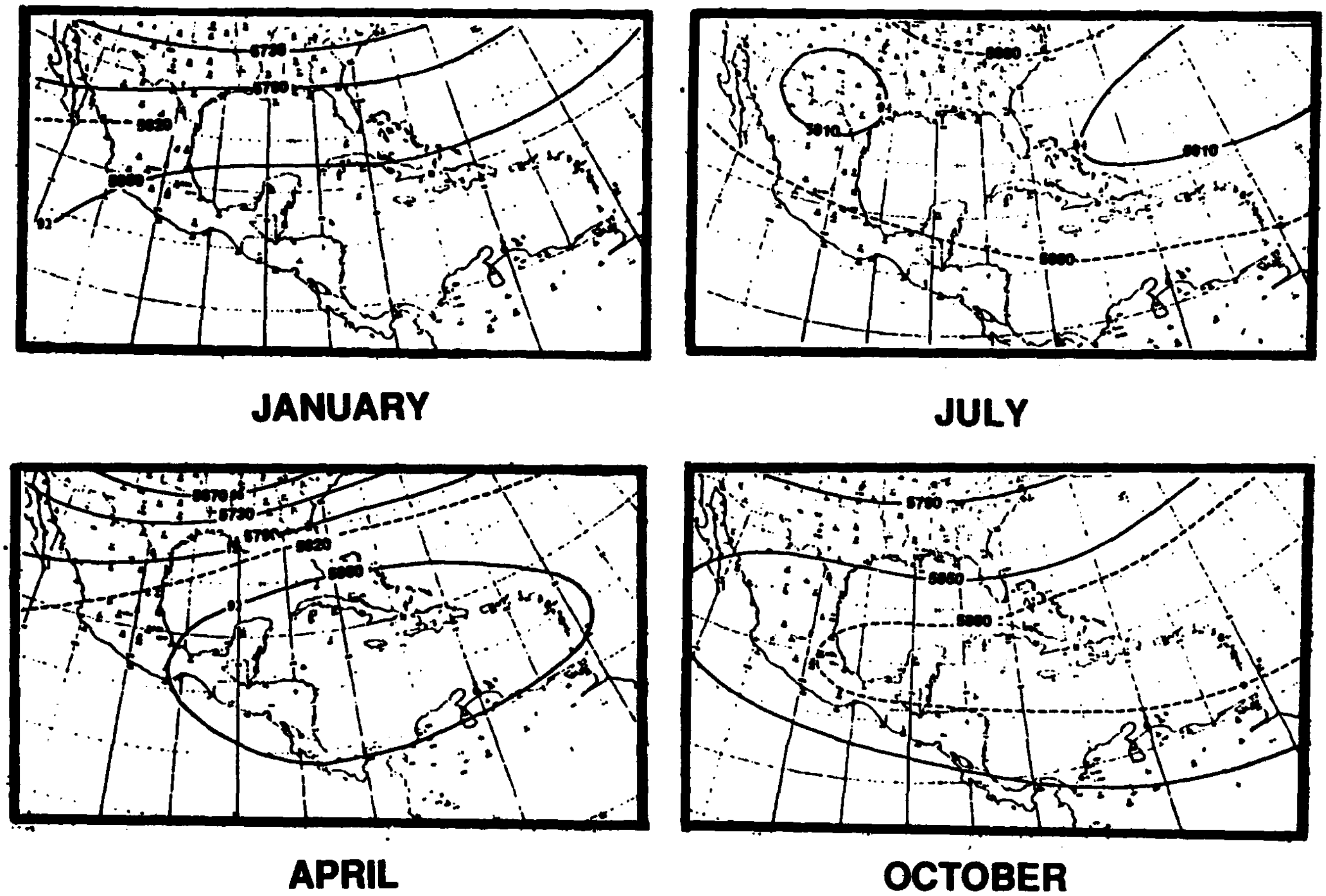

Figure 2-7. Mean Mid-Level (500-mb) Flow, Caribbean Basin. Isopleths are in geopotential meters.

SOUTH ATLANTIC HIGH. Figures 2-8a and 2-8b show mean gradient flow over the Equatorial and South Atlantic for January & April and for July & October. The mean pressure of this southern hemispheric Hadley circulation pattern ranges from 1018 millibars in December to 1025 in July. Extending from Brazil to Africa, the cell migrates northwestward from 32° to 26° S by July and the beginning of southern hemisphere winter. Southeasterly outflow dominates the southern Atlantic basin from 25° S to the equator. Convergence over water is limited to latitudes north of the equator due to mean positions and strengths of both the South Atlantic and North Atlantic Highs. Surface winds originating in the southern hemisphere and feeding into the Monsoon Trough have mean speeds of 6-8 knots in July, and the Trough zone displaces only to about 10° N. Southeasterly trade wind speeds just north of the south Atlantic High, however, average 14 knots. Surface friction reduces these speeds and tends to deflect wind direction towards lower pressure. Like the North Atlantic and North Pacific Highs, this cell slopes westward and equatorward with height. At upper tropospheric levels it becomes part of the Equatorial Buffer zone. See "Semipermanent Climatic Controls--Upper-Level," on page 2-20.

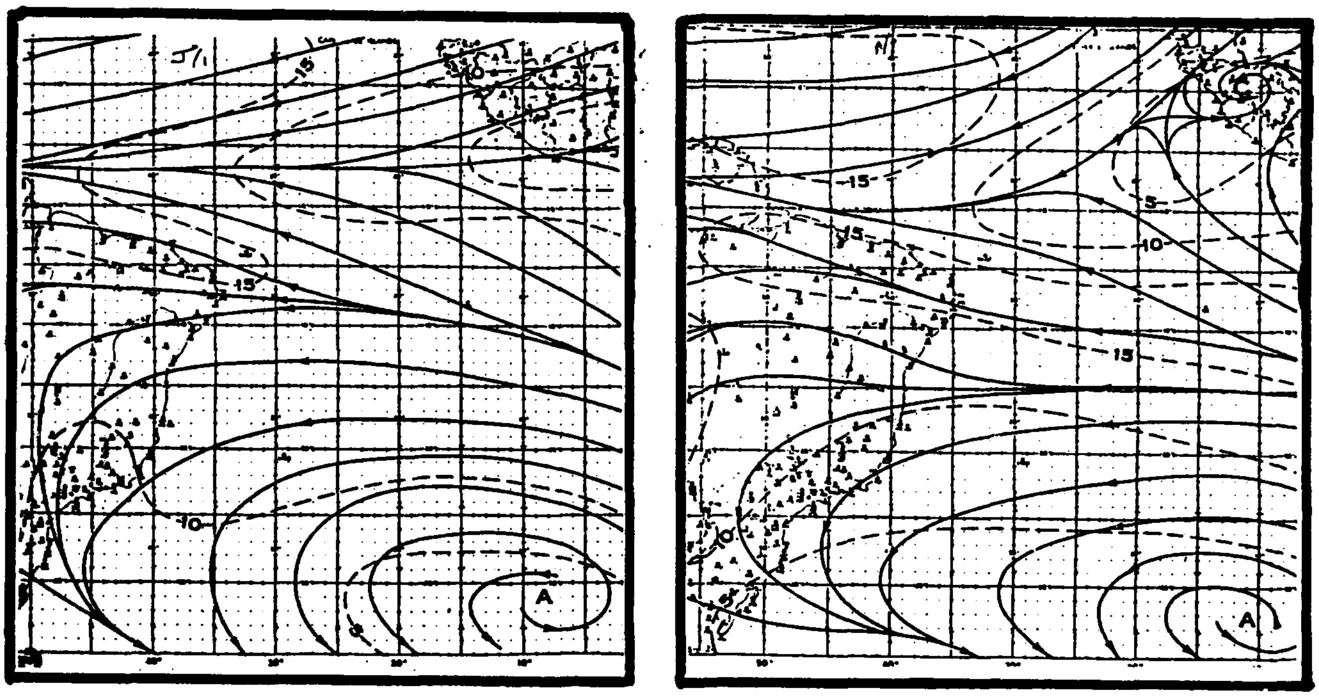

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Figure 2-8a. Mean Gradient Flow, South Atlantic High, January & April.

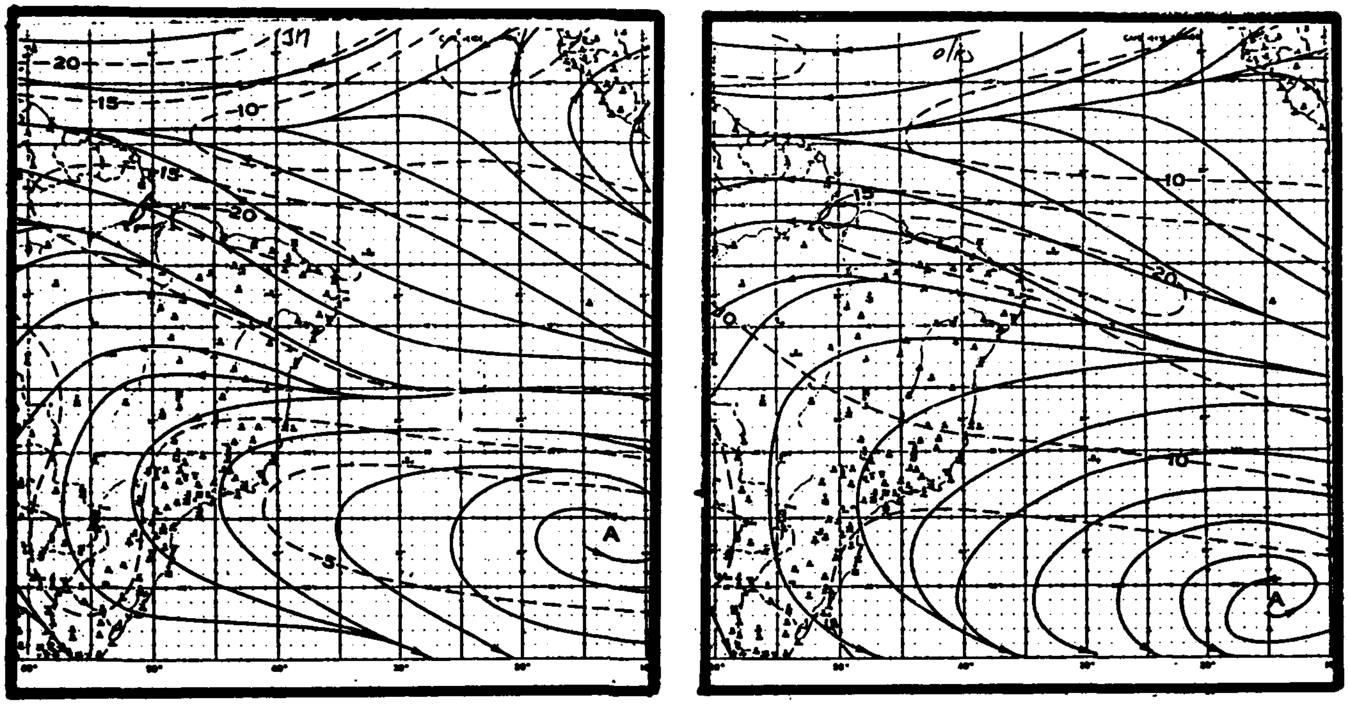

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Figure 2-8b. Mean Gradient Flow, South Atlantic High, July & October.

NORTH PACIFIC HIGH. Representing the descending, northern edge of Hadley cell circulation, this large semipermanent high-pressure system covers much of the eastern north Pacific Ocean. In winter, it extends from the Pacific coast of North America to 160° W, with its center near 30° N, 140° W. In summer, it reaches from the Pacific Coast of North America to near 160° E, with its center near 45° N, 150° W. It affects the Caribbean Basin only indirectly, and then only at mid- and upper-levels during Northern Hemisphere winter. Its major roles are in: (1) developing upper-level westerlies above 10,000 feet (3,050 meters) during the "dry" season (November-April), and (2) providing upper-level shearing that prohibits the northward intensification of Eastern Pacific cyclones in October and November. During June, July, and August, not even upper-level outflow from the North Pacific High system, centered near 45° N, affects the Caribbean Basin. By September, it has started to move southward, reaching near 35° N by early December.

Another major but indirect effect of the North Pacific high is the suppression of cyclone development. The strong fall surges of cross-equatorial flow enhance the equatorial westerlies and provide the Monsoon Trough (now off the western edge of Central America) with extremely moist low-level flow. The southward migration of the North Pacific High allows southward penetration of upper-level westerlies and expands subsidence southeastward into southwestern Mexico. As a result, tropical cyclones spawned from the trough recurve northward more frequently in late October and

November. This puts them into the zone of the westerlies that acts to shear the upper-level storm circulation. The combination of upper-level shearing and cooler sea surface temperatures act to dissipate tropical cyclones north of 30° N.

SOUTH PACIFIC HIGH. This semipermanent Hadley cell is considerably stronger than its South Atlantic counterpart; mean central pressures range from 1025 millibars in July to 1035 in January. This cell plays an indirect role in Caribbean Basin circulation, since its outflow forms the Pacific Equatorial Westerlies. These recurved southern hemisphere winds play a major role in causing the abnormally heavy precipitation of extreme western Colombia and the summer precipitation over western Central America. Reinforcing these winds at 5- to 7-day intervals during southern hemisphere winter are periodic mass surges moving northwestward--and recurving northeastward--that were originally migratory sub-Antarctic polar outbreaks. Blocked in their eastward movement by the Andes, these surges are channeled northward, then northwestward, along the Chilean and Peruvian coasts. No frontal characteristics have been observed north of 20° S. See "Trade Wind Surges" under "Synoptic Disturbances." Figures 2-9a and 2-9b show mean gradient level flow for January & April and for July & October.

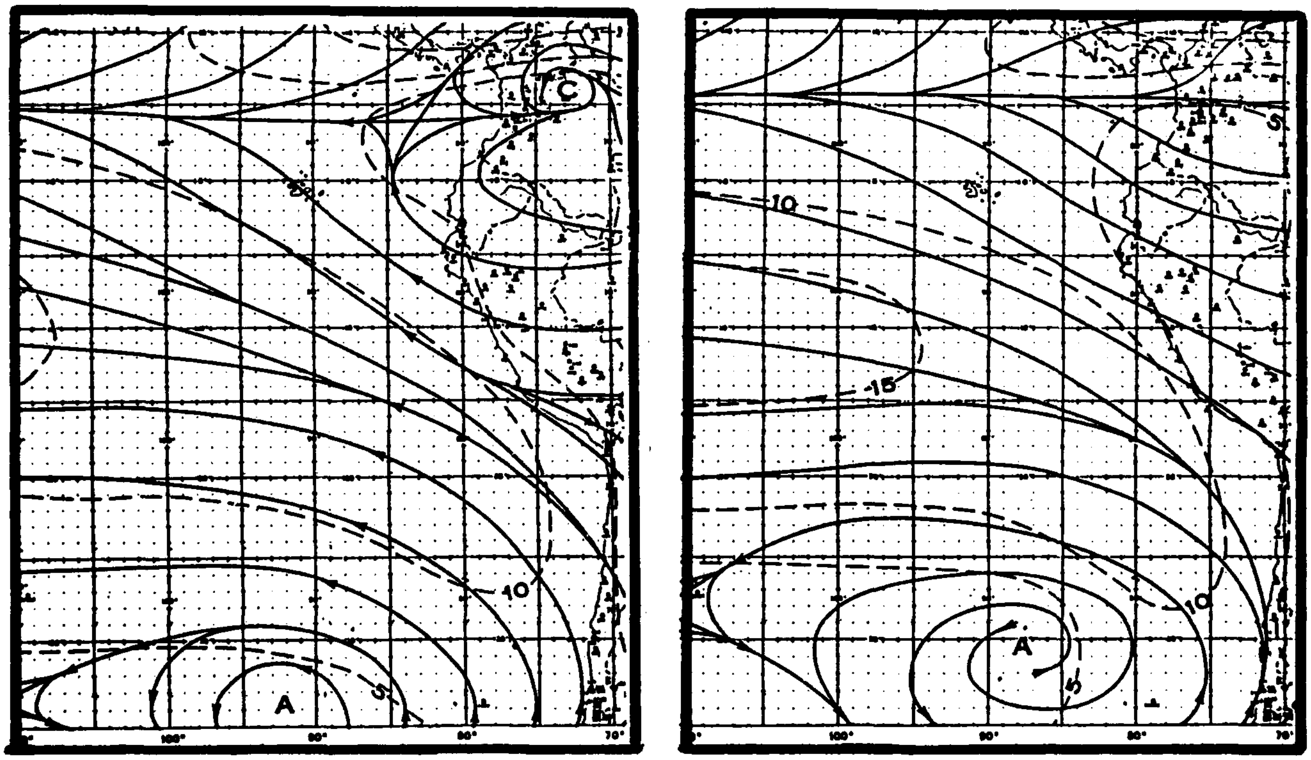

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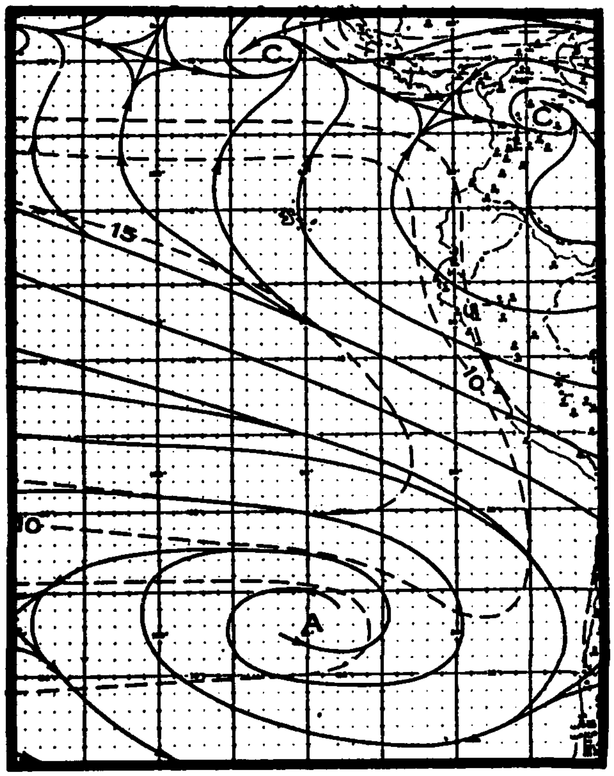
Figure 2-9a. Mean Gradient Flow, South Pacific High, January & April.



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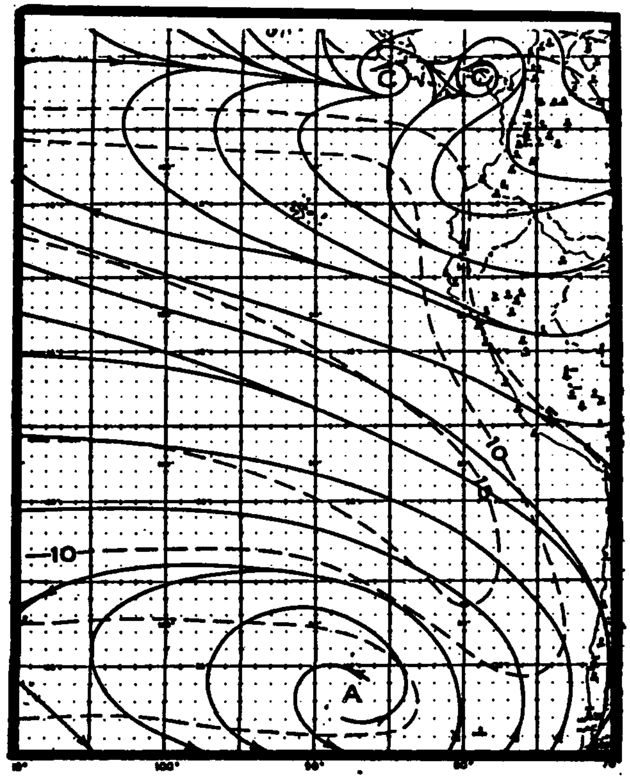


OCTOBER

Figure 2-9b. Mean Gradient Flow, South Pacific High, July & October.

AMAZONIAN LOW. Although this heat low is a semipermanent feature of the Amazon Basin (especially of the western portion), the actual positions of its center vary from summer to winter. Figures 2-10a and 2-10b show mean positions of the Amazonian Low and the Monsoon Trough, as well as mean low-level flow during January and July. Note that the low-level Monsoon Trough, as shown here, is discontinuous at the Andes. Note also that these discussions do not consider the meteorological effects of the ongoing and widespread Amazon Basin rain forest clearing. As of this writing (in early 1989), there had been no definitive studies completed and published by the Brazilian meteorological community.

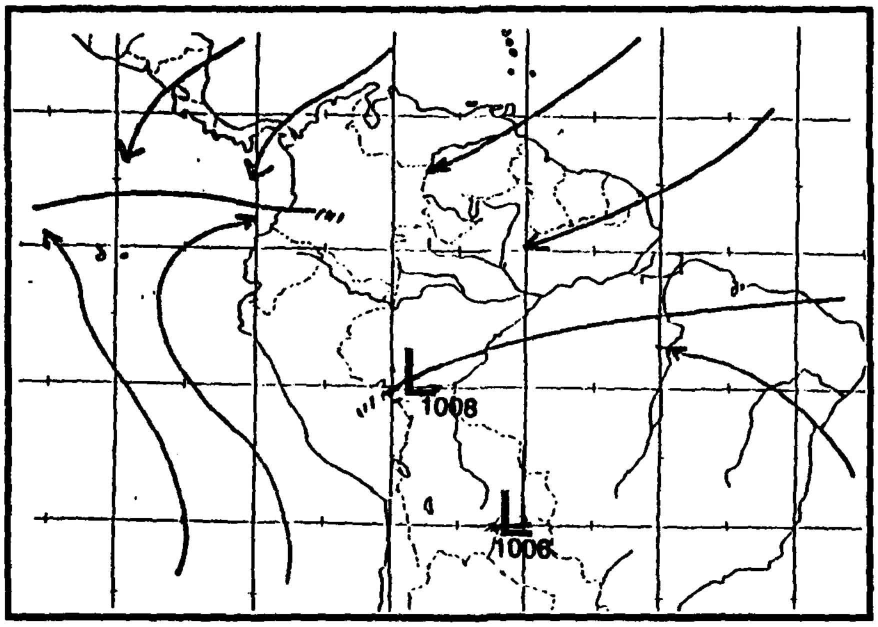


Figure 2-10a. Mean Gradient Flow, Amazonian Low and Monsoon Trough, January.

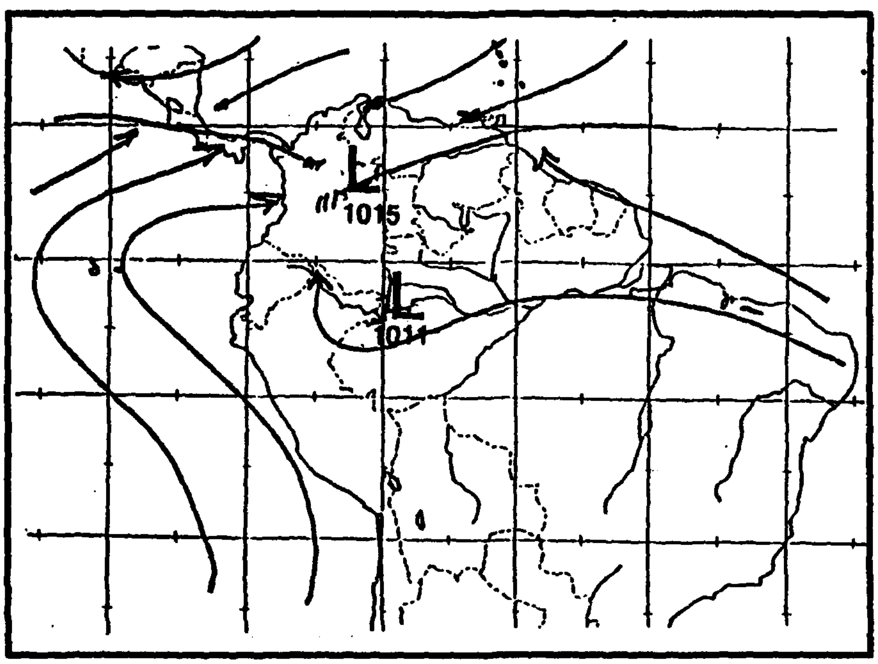


Figure 2-10b. Mean Gradient Flow, Amazonian Low and Monsoon Trough, July.

EXPANDED DISCUSSION--AMAZON LOW AND SOUTH AMERICAN MONSOON TROUGH. The following provides a detailed discussion of the Amazon Low and the South American Monsoon Trough during southern hemisphere summer and winter, respectively.

January-February-March (summer). Because of intense subtropical heating (resulting, in part, from subsidence from the Bolivian upper air high, which see), the low shifts slightly southward and joins the well developed summer heat low centered over southeastern (lowland) Bolivia and northwestern Paraguay near 20° south. Central pressures average slightly less than 1008 millibars. The Monsoon Trough zone that separates northern and southern hemisphere circulations in January (southern hemisphere summer) extends over the entire Amazon basin. The Monsoon Trough (which see) is at its southernmost position in response to the convergent flow of the North and South Atlantic pressure cells as well as to strong latent heat of condensation resulting from intense convection in the southwestern Amazon basin.

July-August-September (winter). The South Atlantic High slowly increases its pressure as it migrates northwestwardly from April until July. Its movement, combined with the northward march of the solar cycle, results in a weaker Amazon low that is confined to the Amazon basin, with mean surface central pressures of 1011 to 1015 millibars. Periodic polar outbreaks reach the Amazon and join with Atlantic high pressure systems in air surging northwestward over the equator. Heavy rain events over Venezuela, and the temporary displacement of the Monsoon Trough into the southern Caribbean result. During such unusual events, southwesterly flow has been observed over southwestern Venezuela. This flow is not considered "equatorial westerly" due to the air's original sub-polar origin. Because of the normal position of the Amazon low, true equatorial westerlies do not occur over the interior of South America.

TRADE WIND INVERSION. A mid-level inversion formed by subsiding North Atlantic High air dominates the entire Caribbean Basin and its coastal fringes. Except in the immediate vicinity of convergence lines and tropical disturbances, this inversion is present all year. Figure 2-11 gives mean trade wind inversion bases for January, April, July, and October over Central America and the Caribbean. Radiosonde information is too fragmentary, and terrain influence too great, to permit extension of this analysis into northern South America.

Inversion strength is weakest (and its presence least likely) from May through October. Mean inversion base heights are 12,000 feet (3,660 meters) at Trinidad, but to the north and west, they average between 8,100 and 9,400 feet (2,470-2,865 meters). Mean thickness ranges from 700 to 1,000 feet (215-305 meters). Mean temperatures within the layer are nearly isothermal.

In midsummer, the inversion briefly strengthens due to a temporary westward migration of the North Atlantic High. This results in a general decrease in both cloud cover and precipitation over the Caribbean Basin and its immediate coasts.

In winter, inversion frequencies and intensities are reinforced by the mid-level (500-millibar) anticyclonic circulation discussed earlier. Temperatures at the base of the inversion average from 1 to 2.5°C cooler than those at the top. The thickness of this inversion layer averages between 800 and 1,400 feet (275 and 420 meters). During winter, bases of the inversion vary from 6,000 to 10,000 feet (1,830 and 3,050 meters) MSL, depending on location.

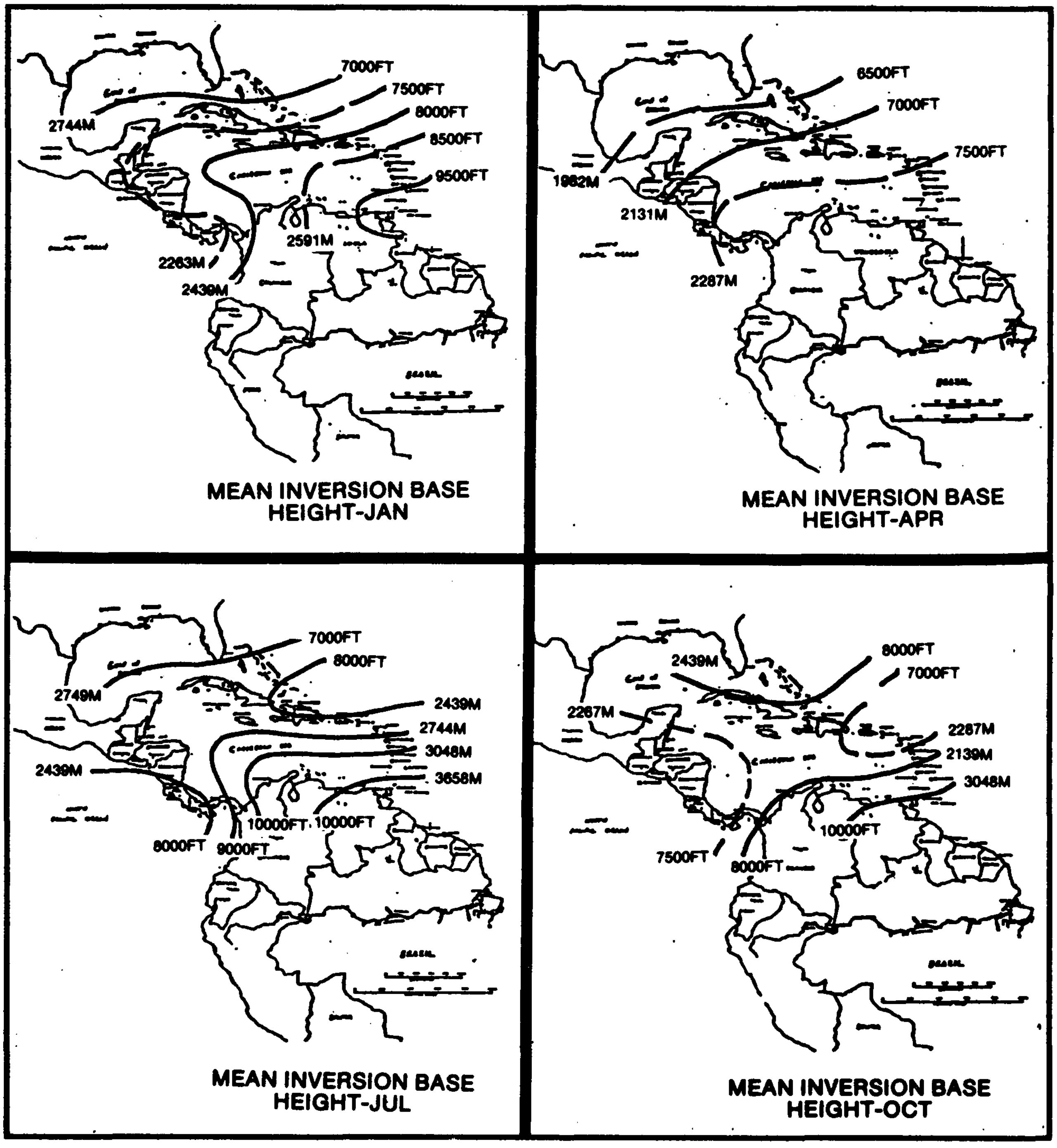


Figure 2-11. Mean Trade Wind Inversion Base Heights.

SEA SURFACE CONDITIONS. Warm sea surface temperatures are extremely important elements in the Caribbean Basin's climate, if for no other reason than that they sustain tropical air masses. The heat capacity of water yields small diurnal and annual sea temperature variations; combined with the high annual solar insolation, the result is a small annual temperature variation. The Caribbean Sea and the adjacent equatorial Atlantic and Pacific oceans are large sources of moisture; the transitory and mesoscale synoptic features that cross the Caribbean Basin tap them effectively. For example, hurricanes characteristically intensify over the warmest water. Conversely, coastlines oriented parallel to prevailing winds produce localized upwelling that, combined with upper-level subsidence and downslope offshore flow, causes rain-fall suppression in the Netherlands Antilles, extreme northern Venezuela, the Colombian Caribbean coast, and the southern coast of Ecuador. Anomalous sea surface temperatures, negative or positive, have large scale weather teleconnections. (See El Nino discussions in the "Northern South America--Pacific Colombian Coast" section). Sea temperatures fluctuate between 75 and 82°F (23 and 28°C) throughout most of the region; however, they drop as low as 70°F (21°C) off the southern Ecuadorian coast in October. Figures 2-12 through 2-15 show mean sea surface temperatures for January, April, July, and October, respectively.

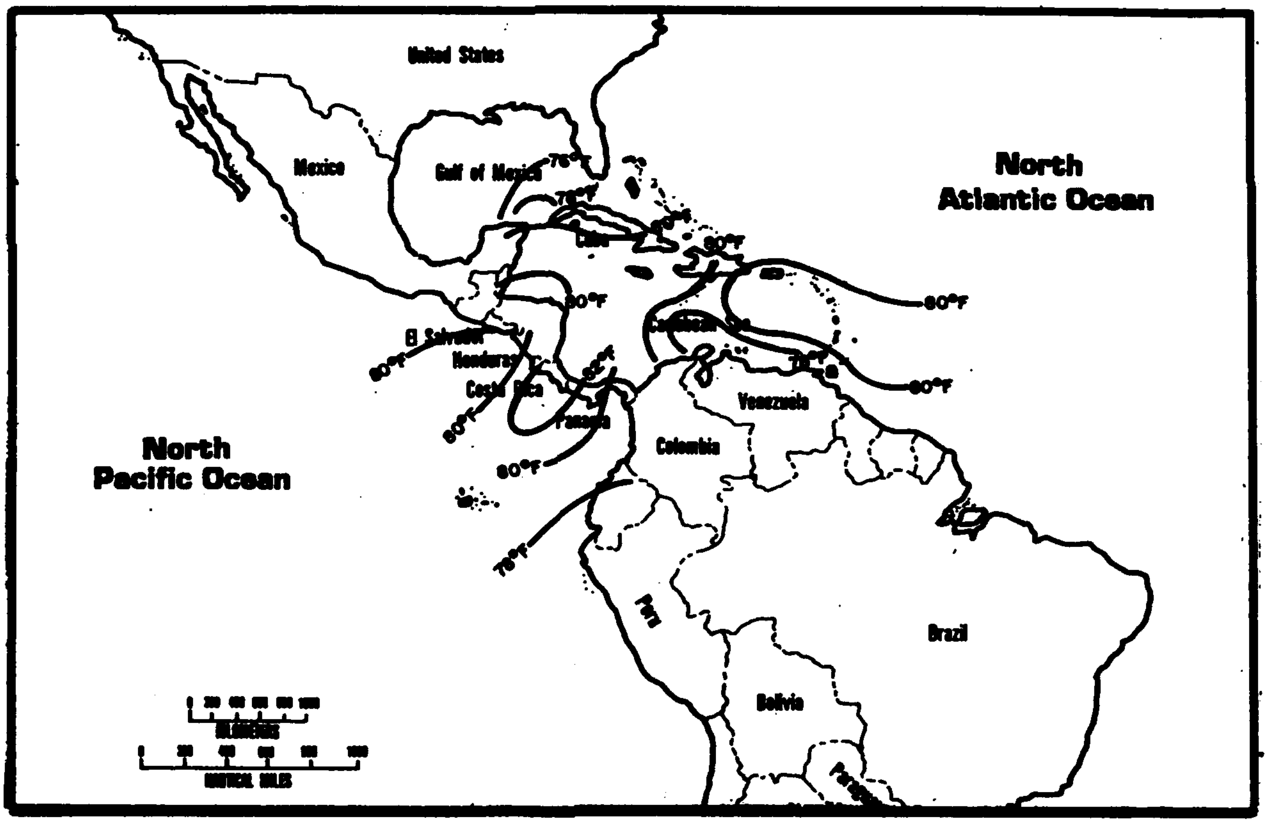


Figure 2-12. Mean January Sea Surface Temperatures.

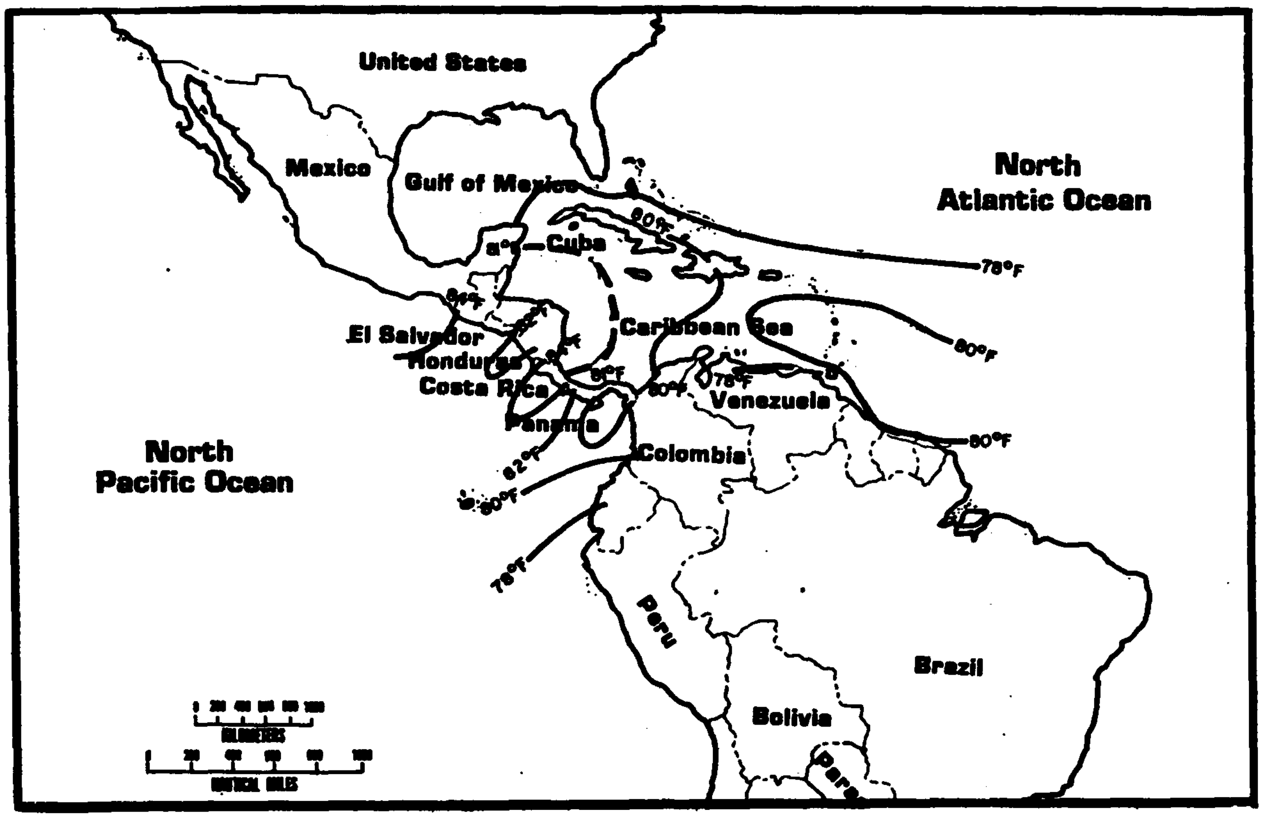


Figure 2-13. Mean April Sea Surface Temperatures.

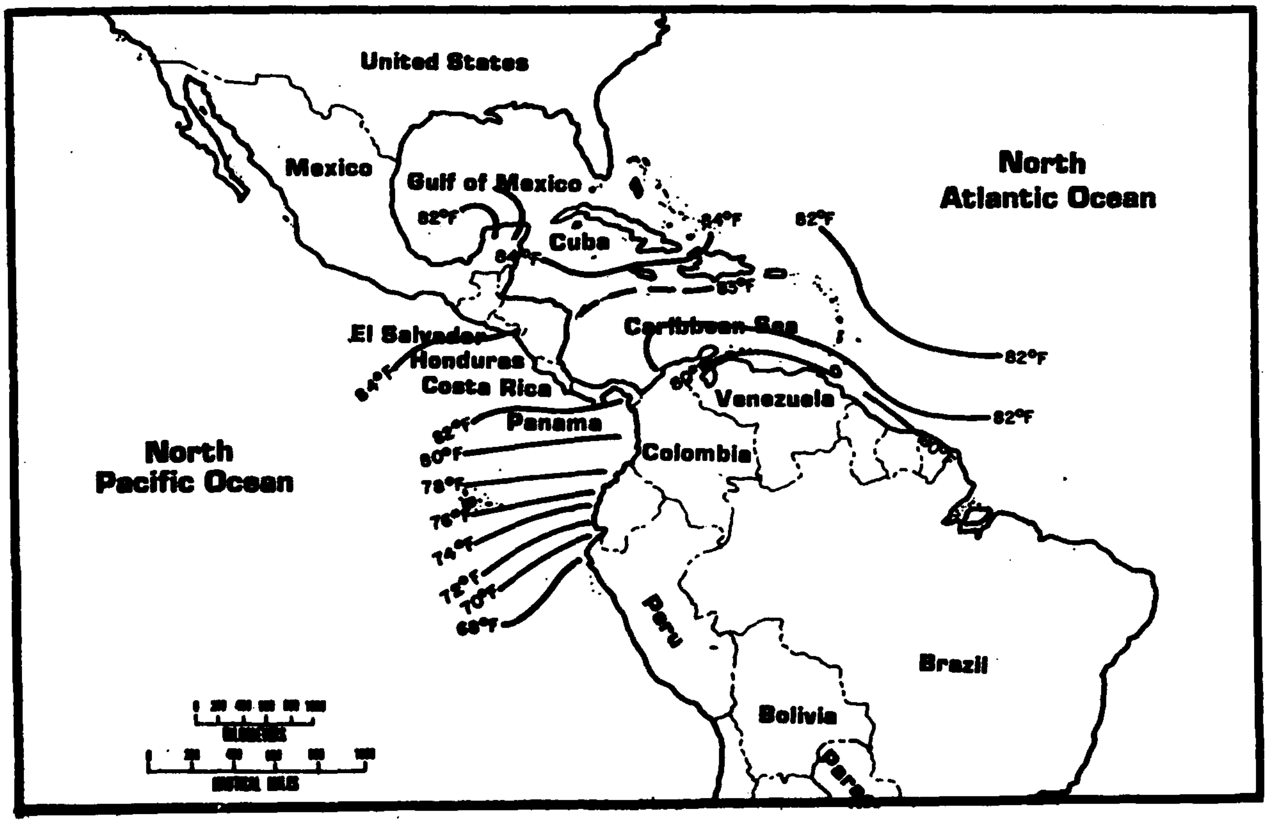


Figure 2-14. Mean July Sea Surface Temperatures.

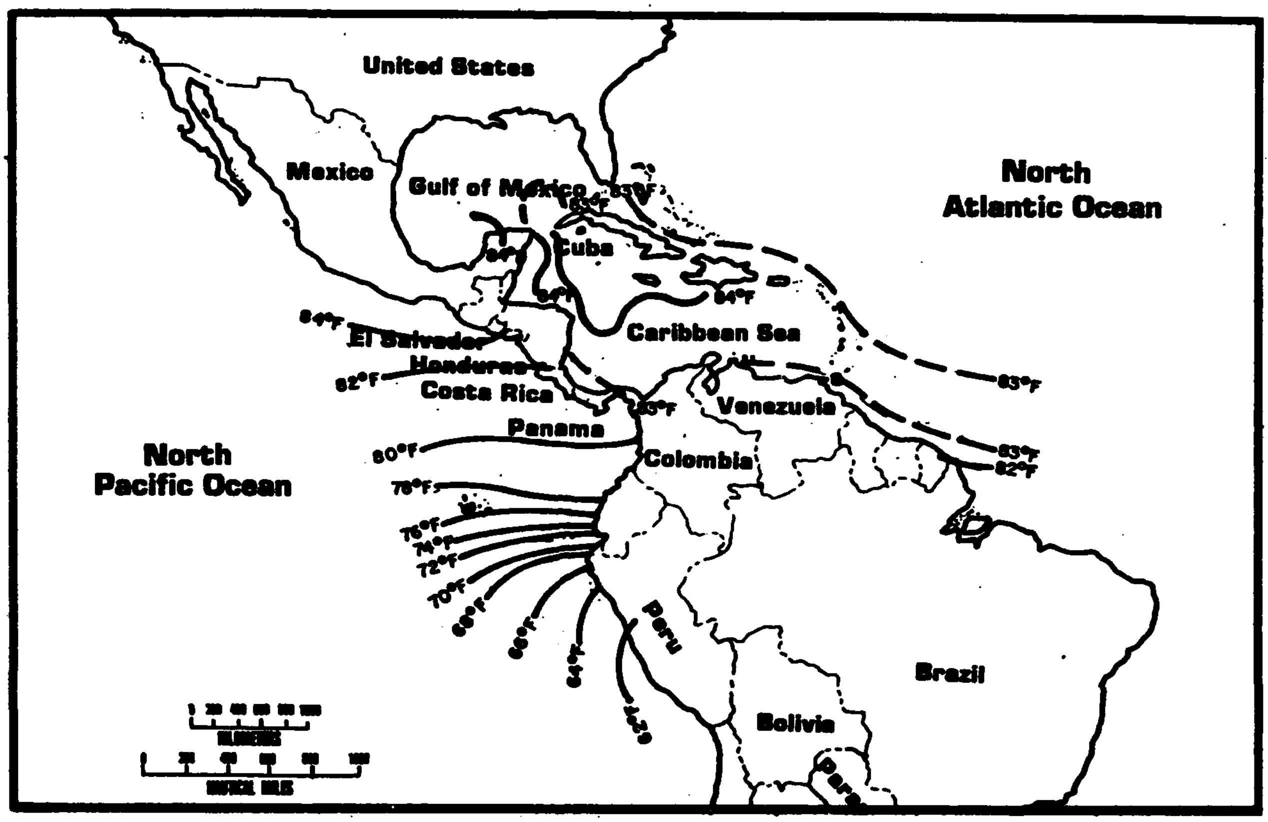


Figure 2-15. Mean October Sea Surface Temperatures.

MEAN UPPER TROPOSPHERIC FLOW. Mean 300-millibar flow for January, April, July, and October over the entire study region is shown in Figures 2-16 through 2-19, respectively.

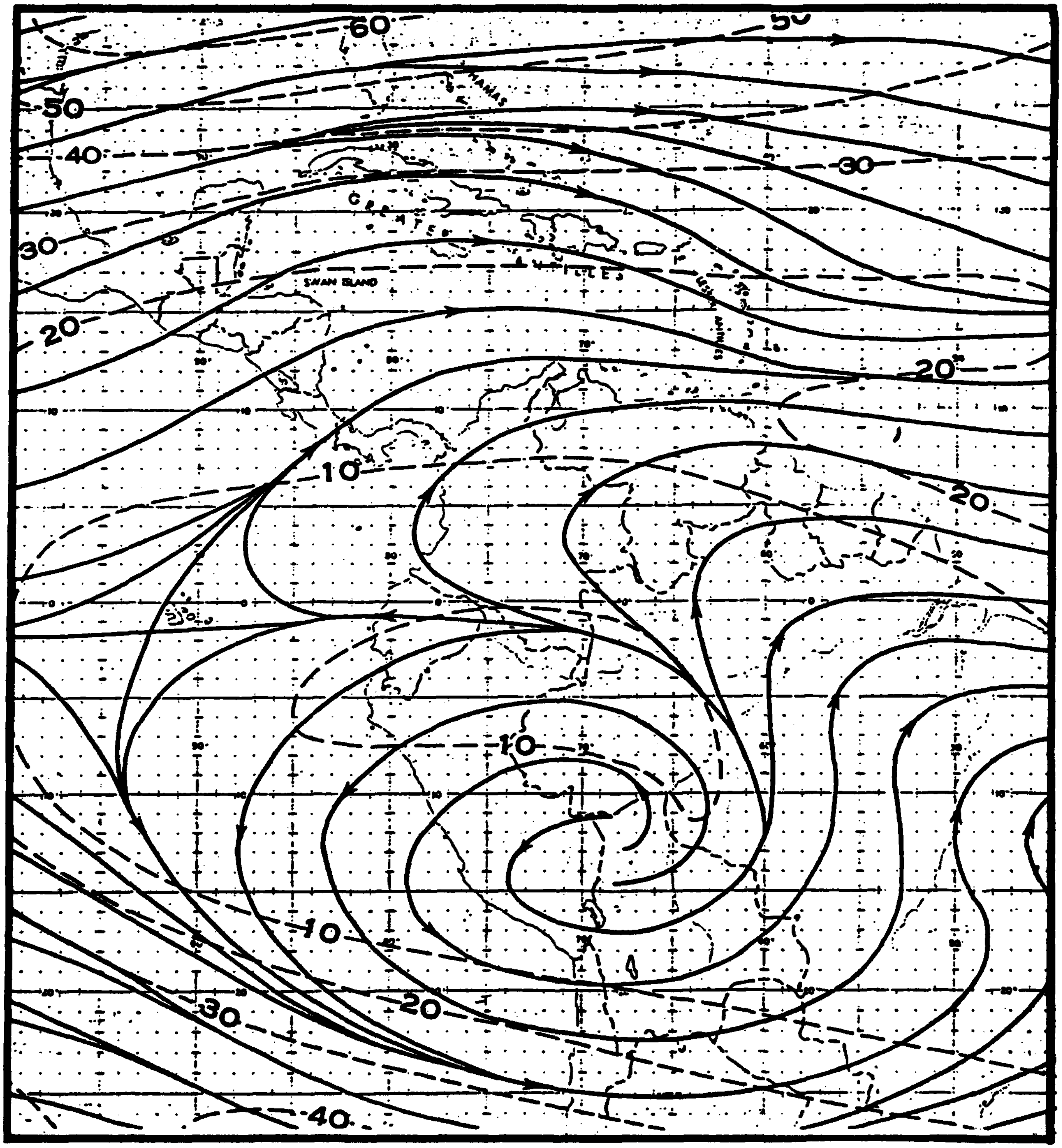


Figure 2-16. Mean 300-millibar Flow, January.

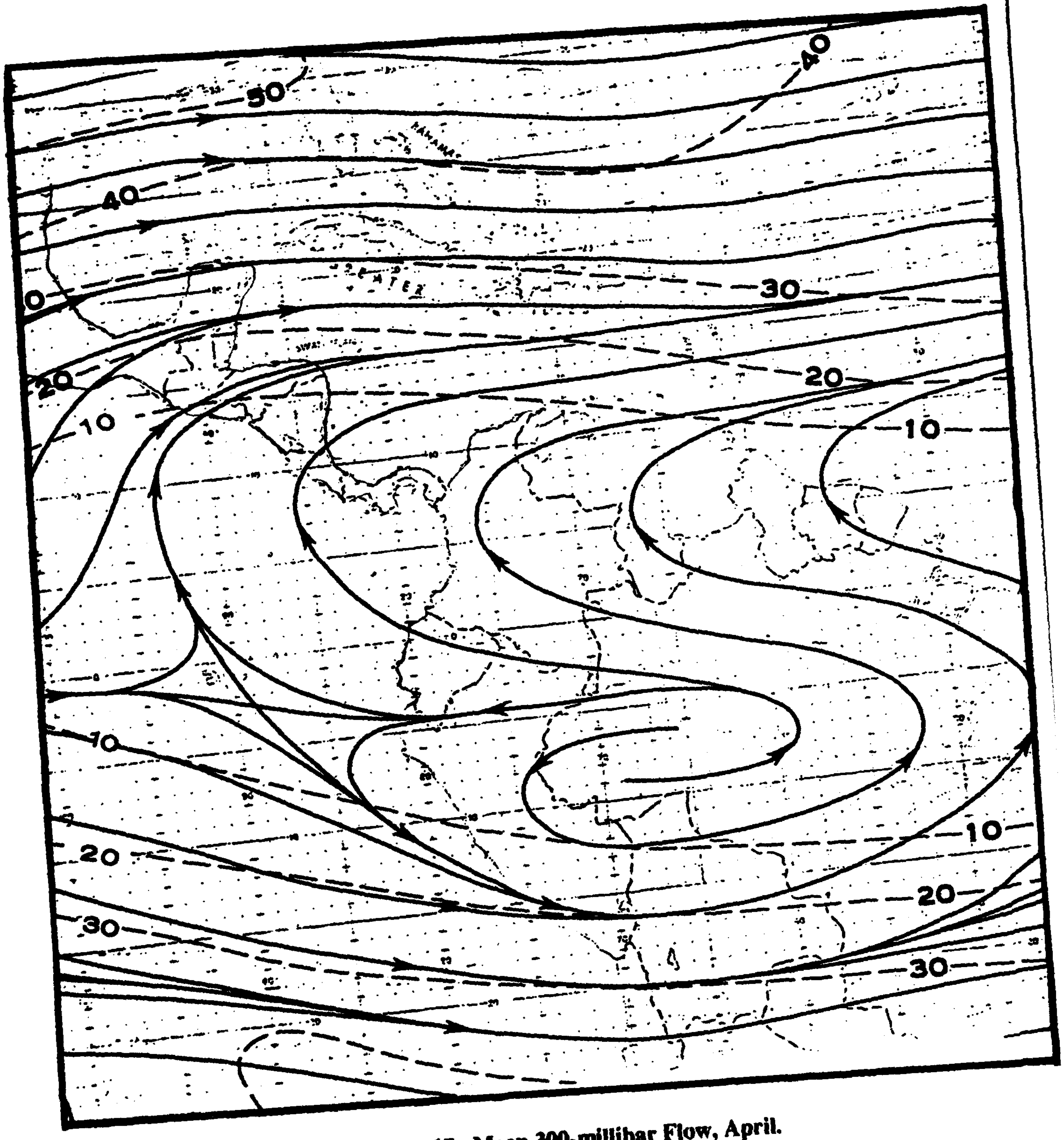


Figure 2-17. Mean 300-millibar Flow, April.

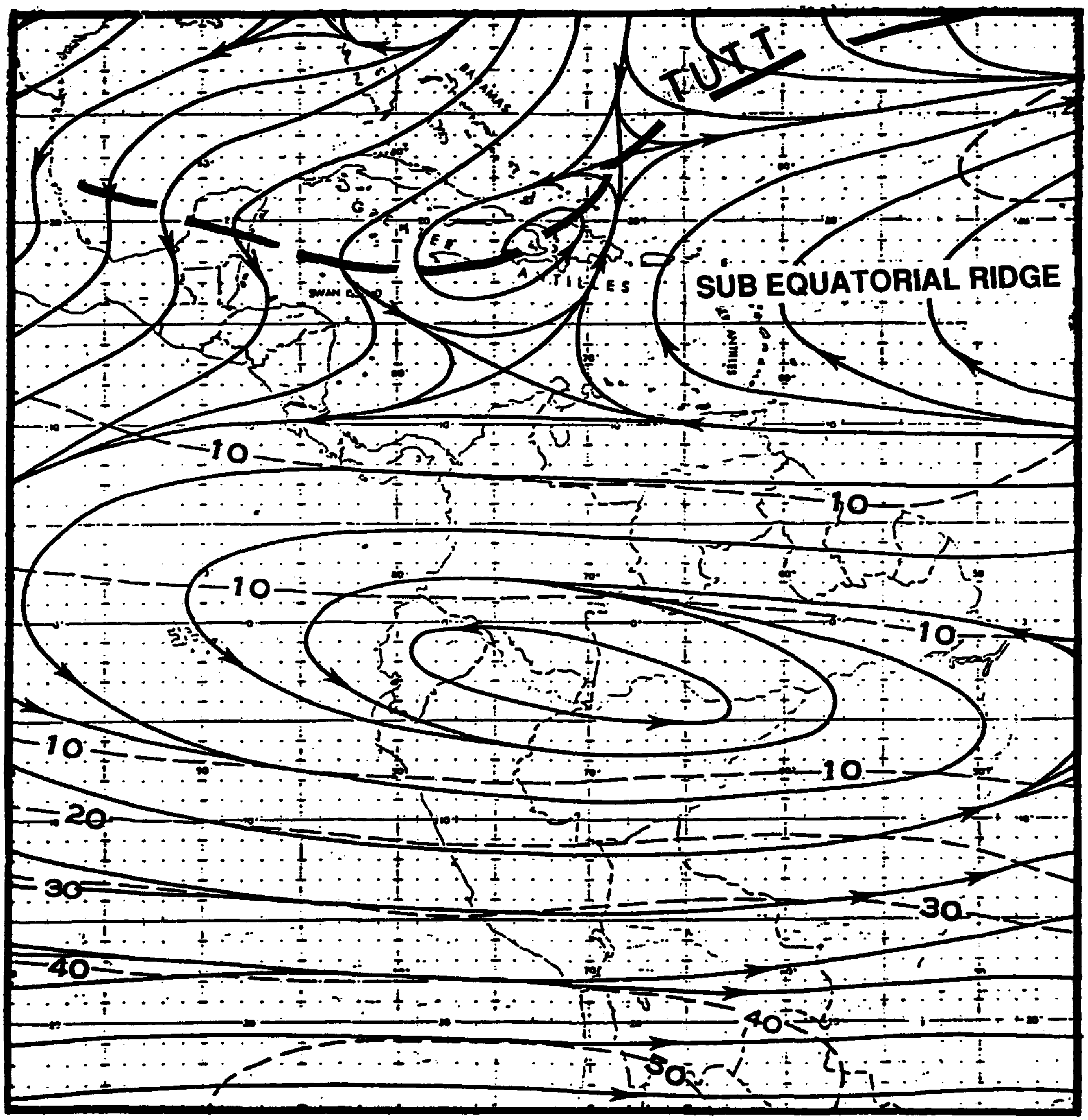


Figure 2-18. Mean 300-millibar Flow, July.

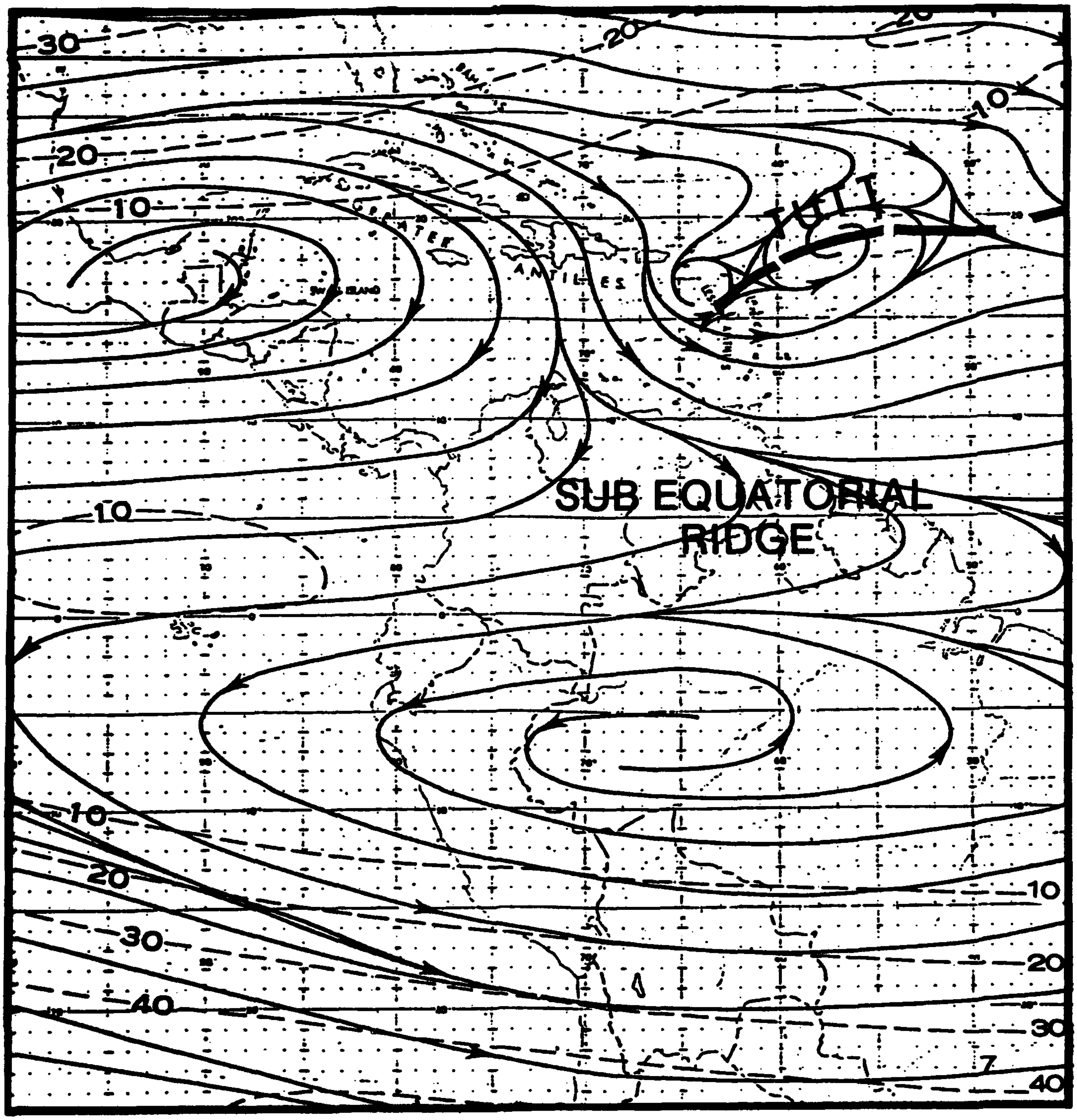


Figure 2-19. Mean 300-millibar Flow, October.

UPPER-LEVEL WESTERLIES. By late autumn, the mean North Pacific High position moves southward, with two results. First, the mid-latitude westerlies start to penetrate the Tropics. Second, outflow from the southeast quadrant of the high results in sustained mean westerly to northwesterly wind directions above 10,000 feet (3,050 meters) west of Central America. This combination periodically reinforces the strength of the 500mb Caribbean Sea anticyclone, a reflection of the low-level North Atlantic High (which see) that develops by late November. Reinforcement normally takes the form of short-wave ridges moving through the westerlies into the Caribbean Sea. As a result, upper-level westerlies between 10,000 and 40,000 feet (3,050-12,200 meters) provide the steering currents necessary to let mid-latitude air masses penetrate deeply into the Caribbean Basin. These ex-polar air masses are the primary weather producers during the dry season in the western Caribbean basin. Mean upper-level westerlies reach 87° 30' W in October, and 80° W by April; refer back to Figure 2-7.

THE MEXICAN ANTICYCLONE (300-millibar) occurs from August through October at upper levels and serves as an exhaust mechanism for northeasterly flow across the Caribbean basin. Strong westerly flow over Canada during summer causes upper-level ridging. This northerly shift in the high-speed westerly flow results in a closed high over the western Gulf of Mexico in July. During October and November, the westerlies shift south. The Mexican anticyclone, weakening as it moves southward, reaches its most southerly position at 15° N before disappearing as closed circulation; by early December, it has been replaced by strong zonal flow off the Pacific. In response to this flow and subsidence from the north Pacific High (which see), a 500-millibar high forms over Central America in January. Refer to Figure 2-19, Mean 300-millibar Flow, October.

SUBTROPICAL JET STREAM (Northern Hemisphere). During winter and early spring, when the high pressure belts are farthest south, westerly winds dominate the Western Caribbean basin above 700 millibars. These high-level winds frequently contain a subtropical jet stream. Upper troughs advect eastward within this current, allowing subtropical cold vortices aloft (or "cut-off lows") to move slowly eastward from the Pacific. Such occurrences are common in late winter with the presence of a 500-millibar anticyclone over northern Central America. The eventual shearing of these troughs by the jet stream isolate "cut off lows" over the western Caribbean and as far south as 12° N. Typical winds within the subtropical jet are between 50 and 110 knots, but speeds above 150 knots are not uncommon around intense troughs.

TROPICAL UPPER TROPOSPHERIC TROUGH (TUTT). The TUTT is an upper-level trough that separates the subtropical ridge from the sub-equatorial ridge in the North Pacific or from the equatorial buffer zone in the North Atlantic near South America. The TUTT is confined, in this study region, to the North Atlantic Ocean and Caribbean Sea (from 10 to 20° N) in northern hemisphere summer and fall. As shown on the 300-millibar mean flow charts for July and October (Figures 2-18 and 2-19), it extends from the extreme northwestern coast of Africa into the extreme southwestern Caribbean. The TUTT enters the study area near Puerto Rico and ends in the central Caribbean north of Venezuela. On occasion, it reaches into the extreme eastern equatorial Pacific.

Mean streamline wind profiles at 300 millibars show cyclonic vortices that vary in both synoptic and seasonal locations. These vortices normally move along the TUTT in a southwestward direction. TUTT-generated cloud systems depend upon available heat and moisture. The TUTT often appears only as a shear line with no large cyclonic cells or with very shallow development within the upper tropospheric layer. However, it may appear at other times as a chain of cyclonic cells hundreds of miles long with deep vertical circulation to the surface. The major cloud systems are south of the trough line. If not directly associated with the cyclonic circulation, they are confined to the westerly flow between the near-equatorial upper level ridge line and the TUTT. The more intense convection is associated with well-developed upper-level cyclonic circulation that slopes vertically towards the southeast with increasing height.

The TUTT's most important role in the Caribbean basin is that of providing outflow channels for organizing convection. TUTT location and orientation also play major roles in the secondary tropical storm/hurricane formation area located in the western Caribbean.

NORTHERN HEMISPHERE SUBTROPICAL RIDGE. This major summer circulation feature produces the middle and upper troposphere steering mechanism for tropical disturbances. Remaining north of 30°, it acts as a formidable northern boundary to tropical storm development.

EQUATORIAL BUFFER ZONE. From January through March, this upper-level zone represents the southern edge of the North Atlantic High. At 500 millibars, it is a closed high-pressure cell over the Caribbean Sea and the western North Atlantic. But at 200 millibars, the ridge has sloped south to form the equatorial buffer zone. In July through September, the situation is reversed; the remains of the Bolivian High have merged with the upper-level portion of the South Atlantic High over northern South America to form the buffer zone discussed here.

SUB-EQUATORIAL RIDGE. This upper-level ridge is similar to, and plays the same role as, the equatorial buffer zone over South America. It is, however, far enough north to lie entirely within the northern hemisphere (as does the Monsoon Trough), hence the name. See Mean 300-millibar flow for October, Figure 2-19.

THE BOLIVIAN ANTICYCLONE (300-millibar). The Bolivian High is formed in January by a combination of heating over the Andes and Bolivian Altiplano and the latent heat of condensation released by intense convection over the western Amazon basin. Much like the Indian-Tibetan summer upper-air anticyclone, this one acts as an upper-level exhaust mechanism for convection. Specifically, the Bolivian High produces a strong divergent upper-level wind field; this divergence is responsible for concentrating surface convergence. Streamlines identify the center at 15° S in January (see Figure 2-16) when the position of the Amazon low and the Monsoon Trough are farthest south over the continent. Through April, the high maintains a closed circulation--see Figure 2-17. Winds at 300 millibars average 30 knots. The high moves north to 5° S by July, weakens drastically, and merges with the South Atlantic High to become the South American portion of the equatorial buffer zone--see Figure 2-18. The upper-level wind field farther south reflects an Andean leeside trough similar to that found east of the Rocky Mountains during Northern Hemisphere winter. The combination favors the equatorward penetration of southern hemispheric winter polar outbreaks.

TROPICAL DISTURBANCES. Under this general heading are discussed the tropical synoptic systems that cause "disturbed weather" in the Caribbean. Most people think of the tropics as having regular diurnal weather patterns that repeat day after day. As might be expected, "disturbed weather" is any condition that is *not* routinely repeated; for example, a rain regime, unusual cloud cover (or lack thereof), abnormal temperatures, drought, and tropical storms. We recognize four general types of tropical disturbances: (1) Trade Wind Surges, (2) Easterly Waves, (3) Subtropical Lows, and (4) Tropical Cyclones, to include tropical depressions, tropical storms, and hurricanes. Each will be discussed in turn.

Trade Wind Surges originate as migratory high-pressure cells that move equatorward around the eastern edge of a semipermanent high-pressure center behind a cold front. The equatorward movement of these cells is often channeled by mountain ranges. As an example, southern hemisphere high-pressure cells moving north are channeled by the Andean ranges and the Brazilian highlands--just inland from the Atlantic coast--into the western Amazon basin.

As these cells penetrate deeper into the tropics two things happen. First, they lose all polar air mass characteristics, and second, the cold front becomes a shear line resulting from the loss of air mass discontinuities across it. As these "cells" move around the semipermanent high-pressure areas, the prevailing winds bring them into the easterly trade wind flow on the semipermanent high-pressure cell's equatorward side. They then move steadily westward until all additional mass has been dispersed sufficiently to dissipate the "cell" or until poleward recurvature occurs around the west side of the semipermanent high.

Surge periodicity, from various studies, is 5 to 7 days. Poleward recurvature of these "mass surges" into the equatorial westerlies is not unusual in the Indian Ocean during the Southwest Monsoon. Such "mass surges" also apparently occur in eastern Pacific Equatorial Westerlies.

In one of the few available studies concerning cross-equatorial surges in this region, Fujita also found a 5- to 7-day surge periodicity. He attributes formation of eastern Pacific tropical cyclones, in part, to deep northern hemisphere penetration of surges in the equatorial westerlies.

Little is known about mass surges moving westward in the southeasterly trades that reach South America. Some Brazilian meteorologists claim that "easterly waves" have been observed in the Natal-Balem area during March and early April, and recent UK research on the weather of Ascension Island substantiates these claims. If the rare phenomenon does occur, it is apparently confined to the fall.

The terrain peculiarities of the Americas--with a massive mid- and low-latitude north-south mountain chain on both continents--dictate that the strongest and most noticeable trade wind surges will be found in the summer hemisphere. The winter hemisphere (again because of the Rocky Mountains in North and Central America and the Andes in South America) has many polar incursions that reach to within 10° of the equator. In the winter hemisphere, therefore, trade wind surges are normally destroyed before they become noticeable. See "Polar Incursions" at the end of this section.

Figure 2-20 is adapted from LeRoux's "Le Climat de l'Afrique Tropical" and illustrates the process in the Atlantic. Note that Professor LeRoux shows this phenomena occurring over the equatorial Atlantic on both sides of the Equator. Some Brazilian meteorologists support his conclusions. A similar process is believed responsible for pulses in the eastern Pacific Equatorial Westerlies, but studies of the south Pacific high west of South America are too few to draw definitive conclusions. Fujita's pioneering study of the equatorial eastern Pacific westerlies supports such a trade wind surge origin. Figure 2-21 shows the progression of these surges in the Pacific.

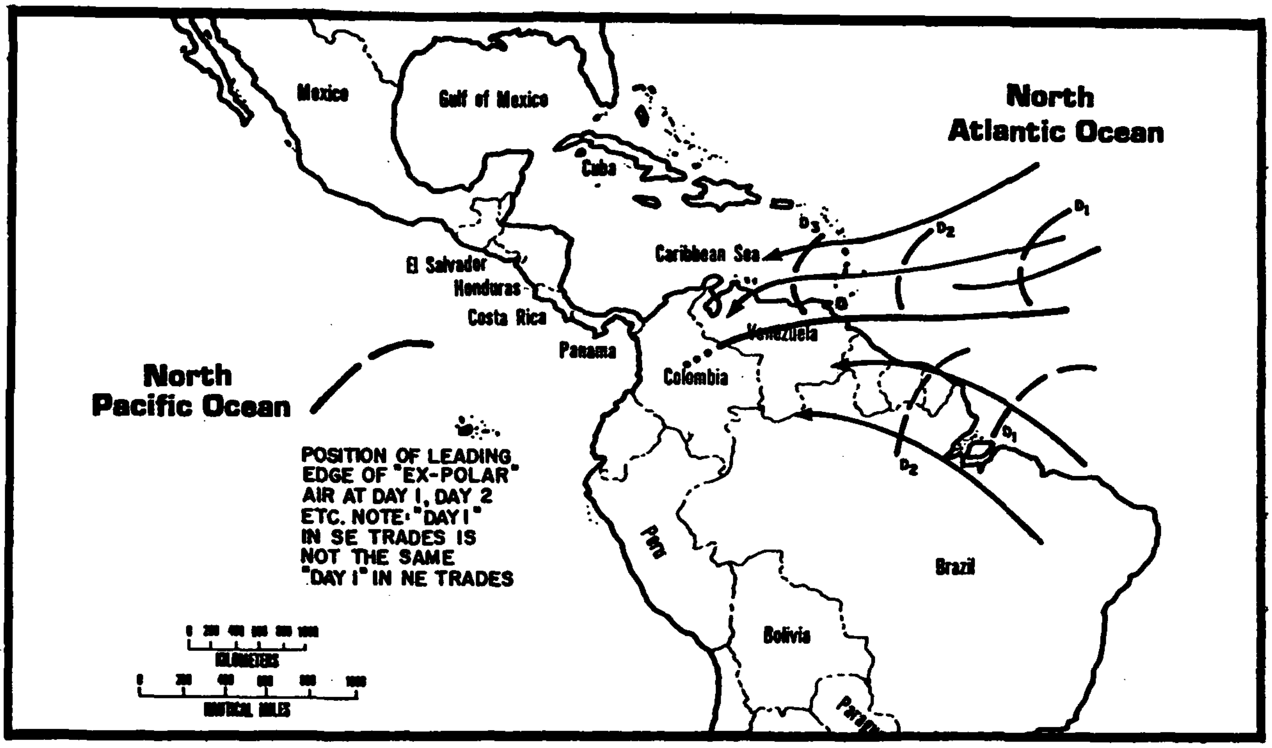


Figure 2-20. Trade Wind Surges in Northeast and Southeast Atlantic Trades.

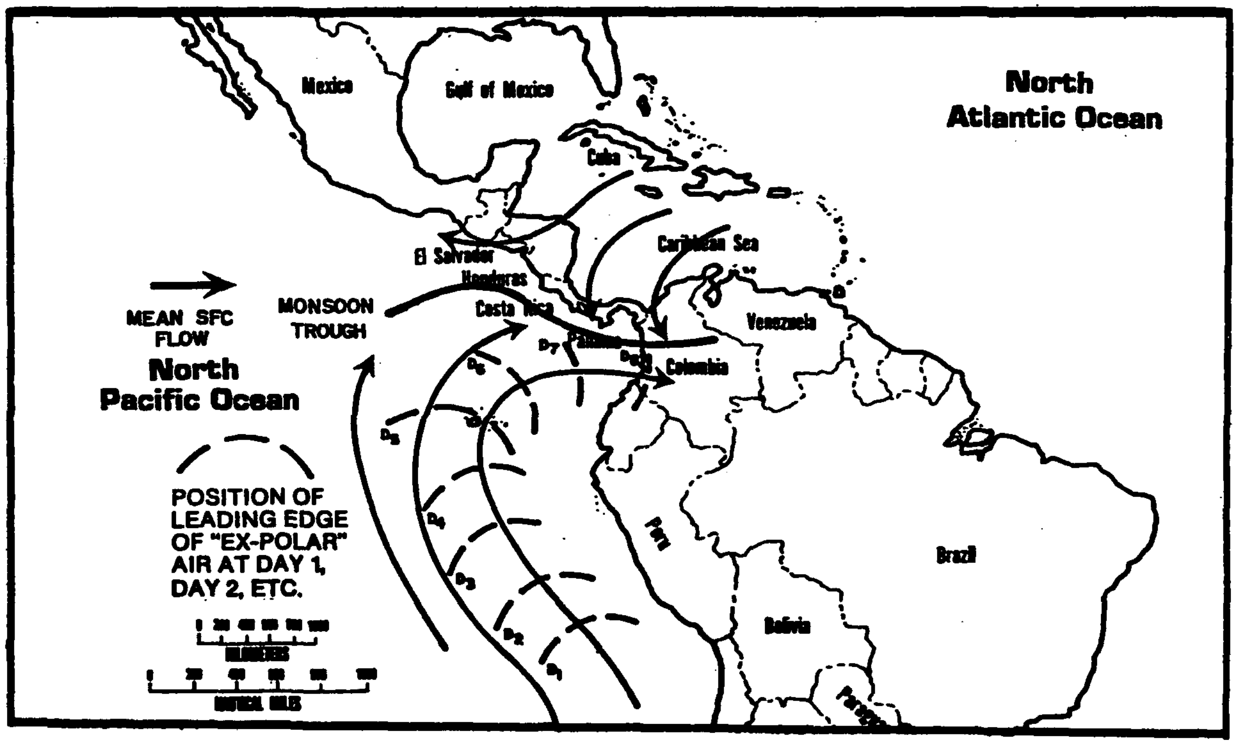


Figure 2-21. Trade Wind Surges in Southeast Pacific Trades.

Easterly Waves. A number of studies, pro and con, have been done on the easterly wave phenomenon since Riehl discovered it just after World War II. The classic easterly wave takes the shape of an inverted "V" in deep easterlies and extends upwards to 30,000 or even 40,000 feet (9.15 to 12.2 km). The trough curves northeastward; slope with altitude is towards the east. Greatest circulation appears to be at 850 millibars. Figure 2-22, adapted from Riehl's "Tropical Meteorology," shows the classic Caribbean easterly wave structure.

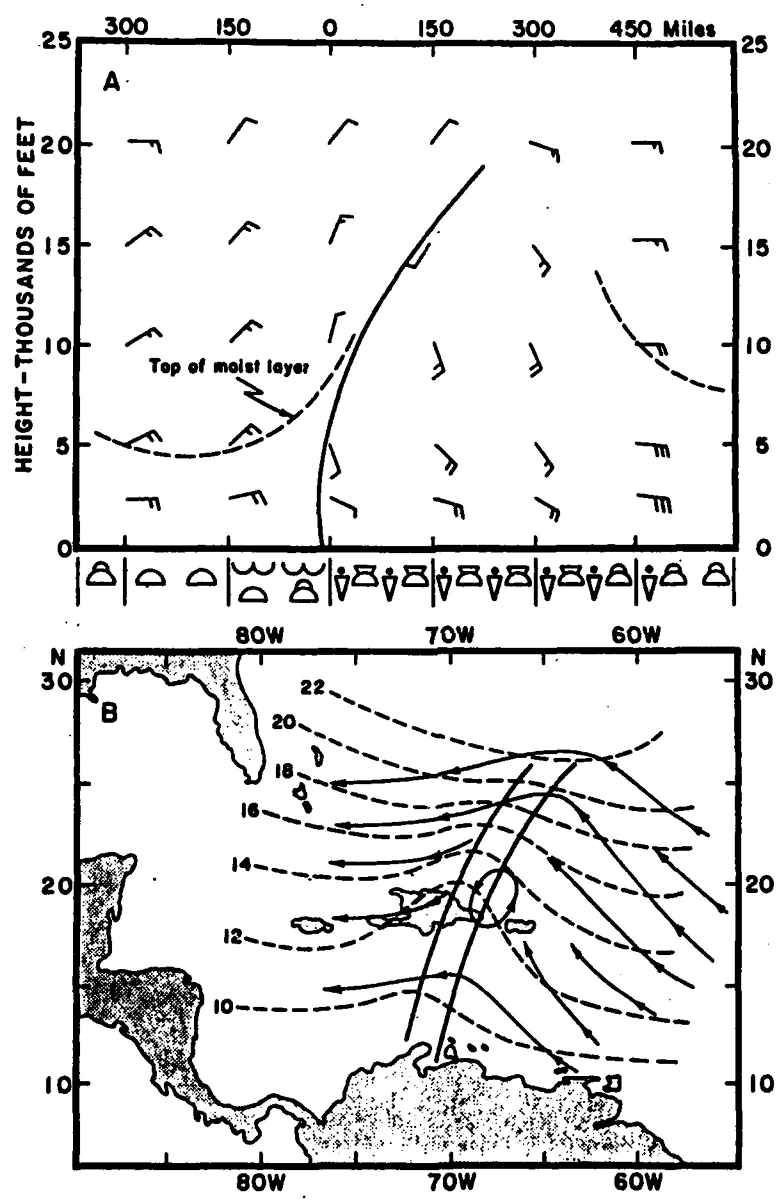


Figure 2-22. Caribbean Easterly Wave Structure (from Riehl).

Figure 2-23, adapted by Riehl from a study done by Reed et al using GATE data, shows horizontal flow patterns for four levels in the atmosphere. Although the patterns shown are not from the Caribbean, Riehl believes them to be representative of Caribbean easterly waves, as well.

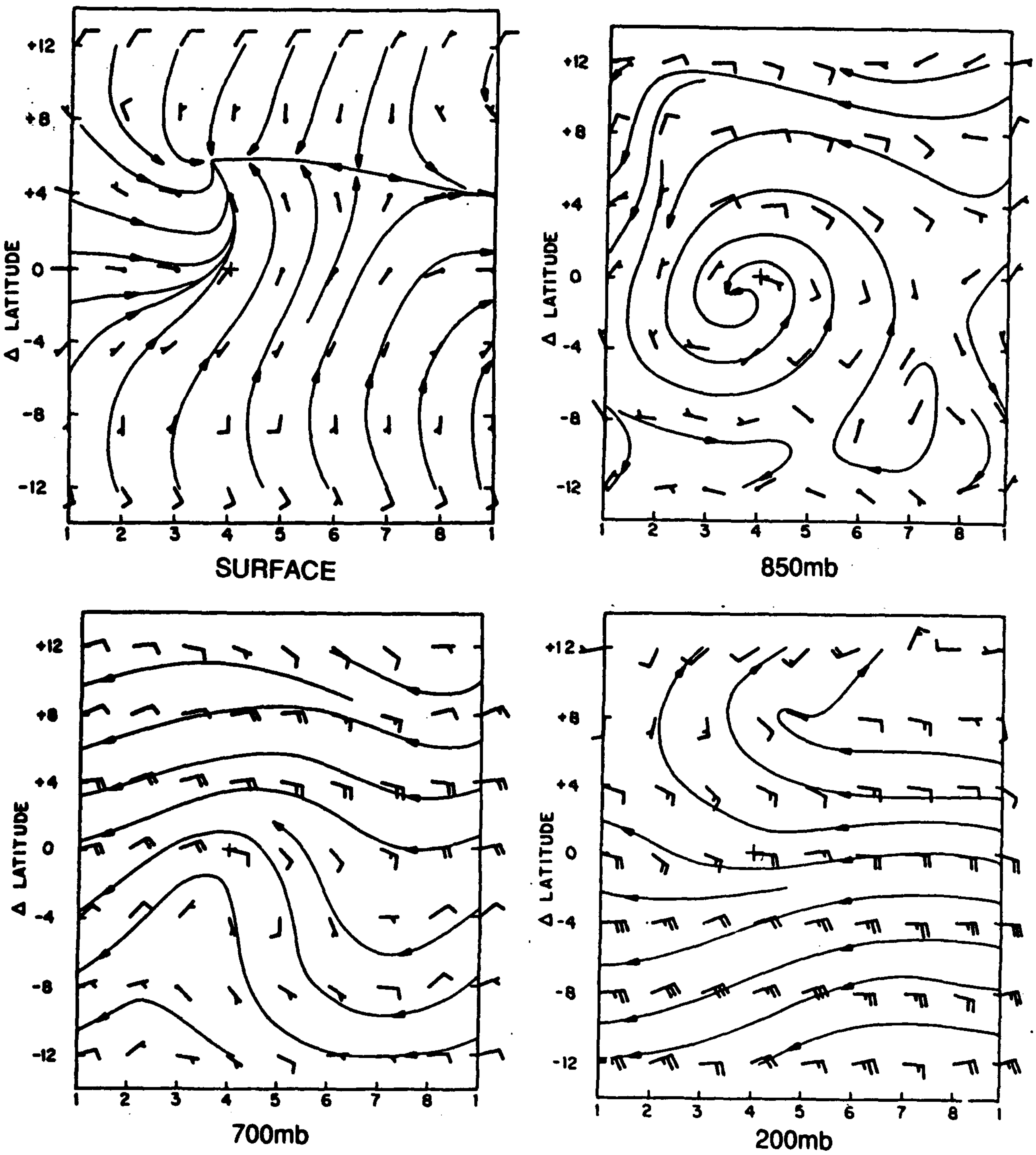


Figure 2-23. Typical Horizontal Flow Patterns Associated with Easterly Waves. Category separation is about 3 degrees longitude. The cross denotes the disturbance center at 700 mb. One full barb equals 5m s^{-1}, a halb barb 2.5 m s^{-1}, and no barb 1 m s^{-1}.

Research since Riehl's pioneer efforts has revealed permutations of the original concept. For example, it was discovered shortly after World War II that the precipitation occurred ahead of the wave trough whenever the upper-level easterly flow is stronger than the low-level flow, causing the trough to slope westward with height. A major variation on Riehl's easterly wave structure is the "inverted V" (apparently nothing more than an enhanced easterly wave) shown in figure 2-24. The term for this phenomenon was coined by Frank and his fellow forecasters at the U.S. Weather Bureau's Miami Hurricane Center immediately after the acquisition of satellite imagery became routine. The name comes from the enhanced cloud distribution poleward around the inverted trough.

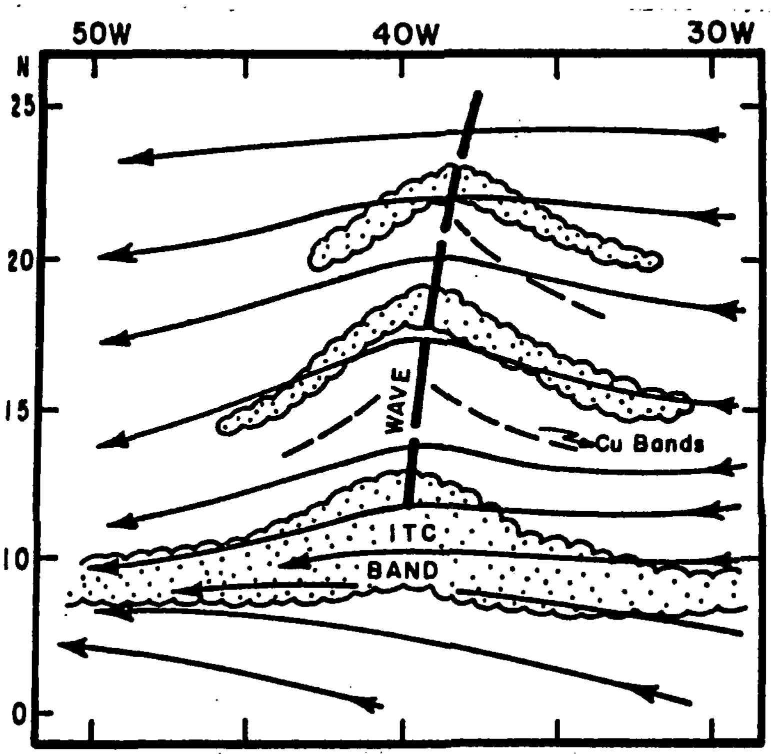


Figure 2-24. The "Inverted V" Phenomenon.

Easterly waves seem to be found primarily in the western equatorial north Atlantic, the Caribbean, and the western equatorial north Pacific. Strongest intensities occur when a very low-level westerly wind layer (100 to 150 mb deep) is present. Such events occur in the monsoon trough, where equatorial westerlies provide such flow, or on a temporary basis in deep easterly trade flow due to local circulation around the wave. Other tropical oceans see only an occasional easterly wave, and even the three areas mentioned here often see "spells of disturbed weather" that don't fit the easterly wave model. It now appears that the easterly wave is only one type of tropical disturbance resulting from a trade wind surge. It is common enough in the three areas mentioned to warrant special identification and tracking. In other areas, it is recognized when it makes an infrequent appearance. (One surmises that it would not have been identified as "the synoptic model" had it not been observed in a relatively data-rich area--one having relatively large numbers of upper-air soundings and numerous aircraft reports--at a time when a large concentration of newly-trained meteorologists' immediate career progession depended upon being able to make accurate tropical weather forecasts for routine military operations.)

Subtropical Cyclones. As the name implies, these upper-air circulations are normally found between 20° and 35° poleward of the equator in either hemisphere. Known for years in the Hawaiian Islands as "Kona lows," subtropical cyclones originate as mid-latitude upper-level lows. After being cut off from the high-speed westerlies, some will drift southeast or south into the tropics. At this point all circulation occurs above 700 mb, with the maximum usually about 400 mb; low-level circulation is almost non-existent. The cloud shield consists primarily of middle clouds and cirrus, with some heavy cumulus and a few embedded cumulonimbus near the low center. Latent heat of condensation gradually transforms these lows into warm cored systems; when this happens, they normally fill and dissipate. The subtropical cyclone is believed to be partly responsible for Central American "temporales." On rare occasions, they have been transformed into tropical cyclones, an event that requires the simultaneous presence of a low-level disturbance (easterly wave or squall line) moving into the subtropical cyclone circulation field with enough strength to reinforce the subtropical cyclone circulation. Figure 2-25 shows a typical subtropical cyclone.

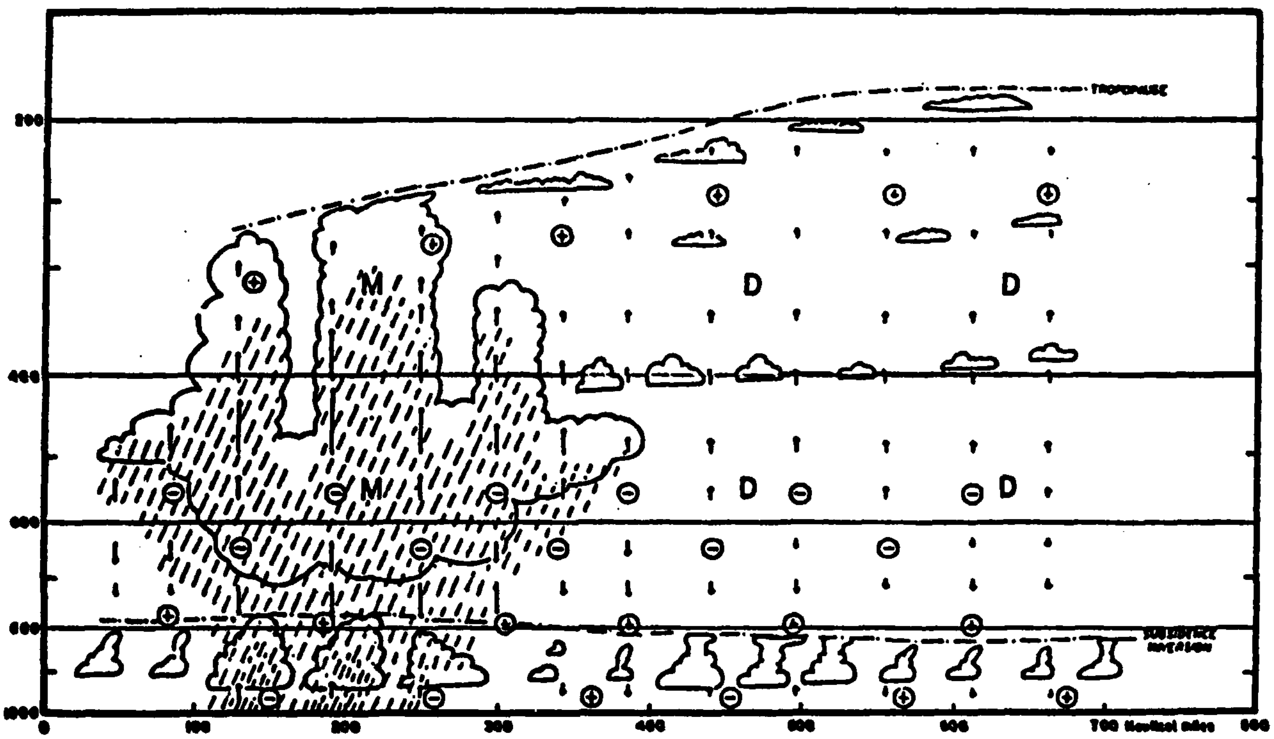


Figure 2-25. Radial Cross-Section, Typical Subtropical Cyclone. Severe constriction of the horizontal scale allows only features of the vertical motion and cloud systems to be shown. *Divergence* is indicated by plus signs, *convergence* by minus signs. Regions of vertically moving air undergoing *dry* adiabatic temperature changes are denoted by D; regions undergoing *moist* adiabatic temperature changes are denoted by M.

Tropical Cyclones. In the Caribbean Basin, tropical cyclones commonly form over warm (81°F/27°C or warmer) water and in a relatively unsheared vertical wind structure. Given these conditions, any one of the following may act as a trigger: (1) a west African squall line, (2) an easterly wave, or (3) a TUTT cyclone. In the first two cases, sufficient outflow must be present above the top of the developing tropical cyclone to sustain the enhanced convection. TUTT cyclones--similar to subtropical cyclones--provide initial outflow for enhanced convection to form. This convection, by latent heat of condensation, then forms a high-level anticyclone near the TUTT; this further enhances outflow, which enhances convection, and the cycle repeats. Figures 2-26, 2-27, and 2-28, adapted from Atkinson, Riehl, and Atkinson, respectively, show a tropical cyclone vertical cross section, horizontal low cross section, and high-level horizontal cross sections.

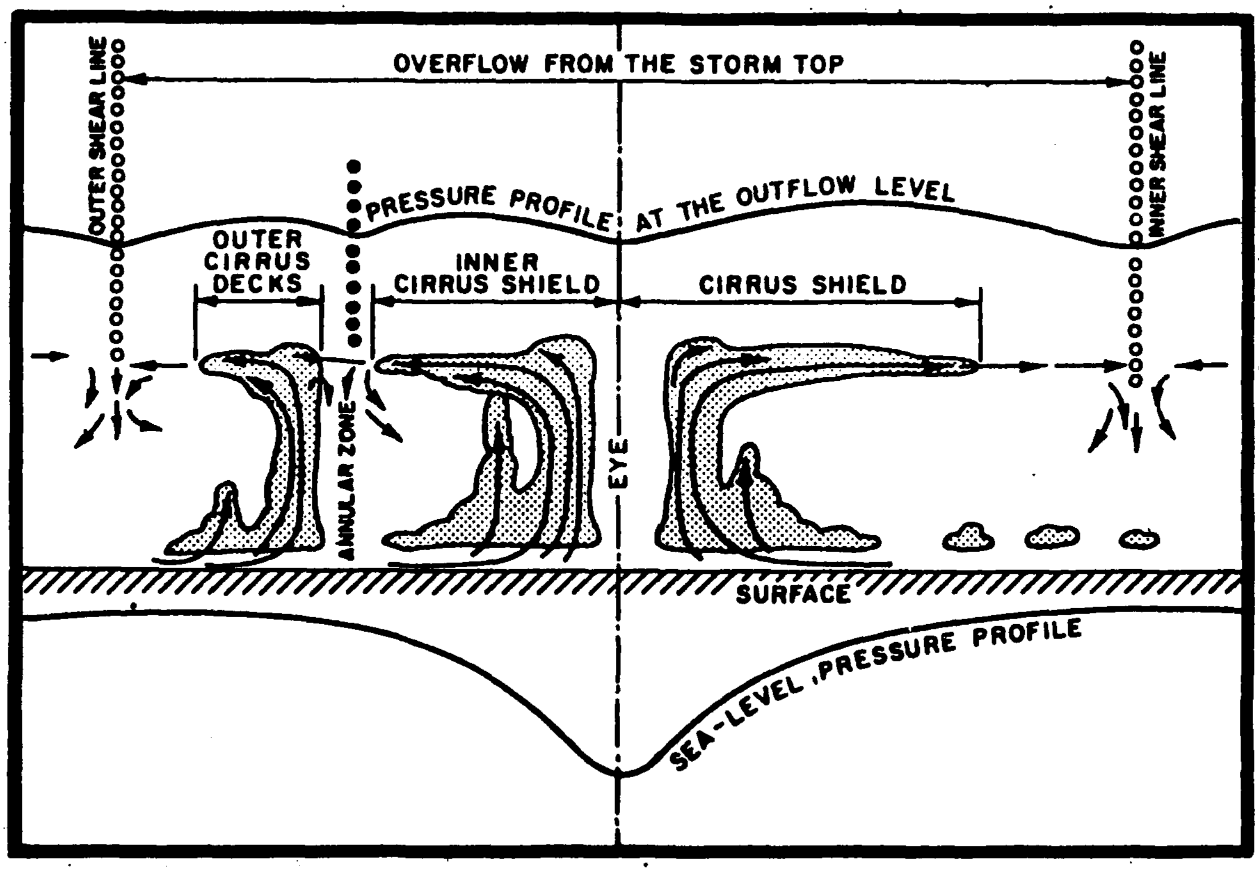


Figure 2-26. Tropical Cyclone Vertical Cross-Section.

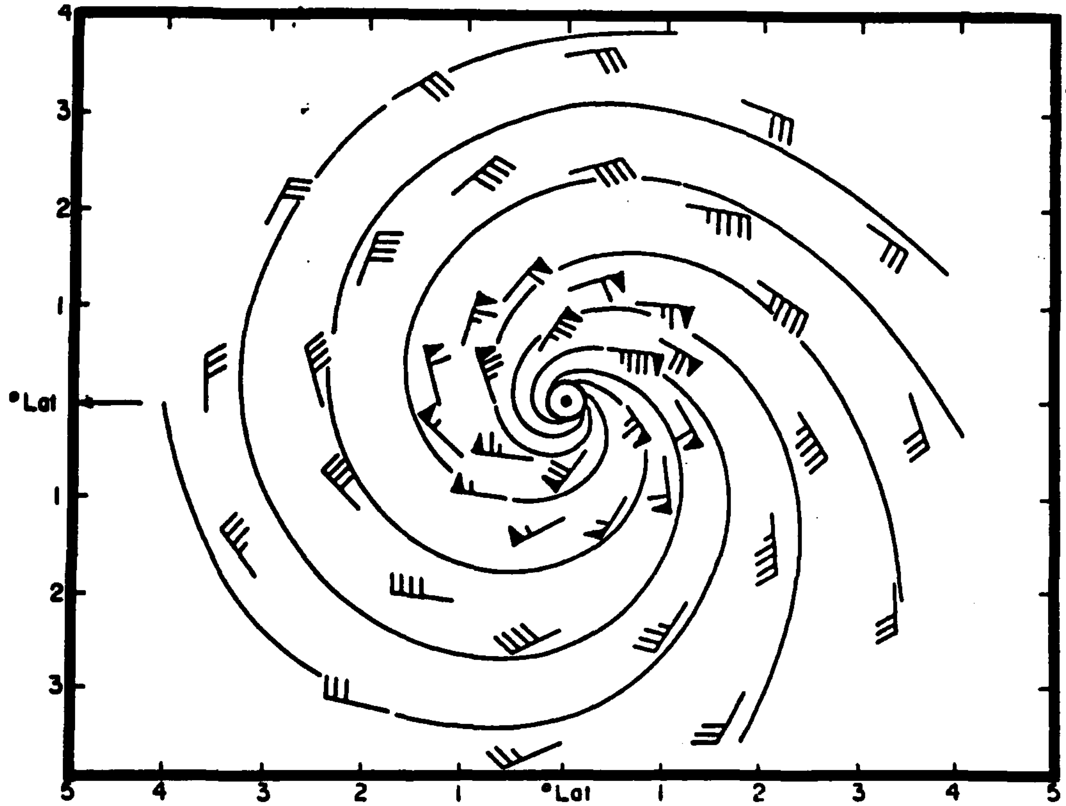


Figure 2-27. Tropical Cyclone Low-Level Horizontal Cross-Section.

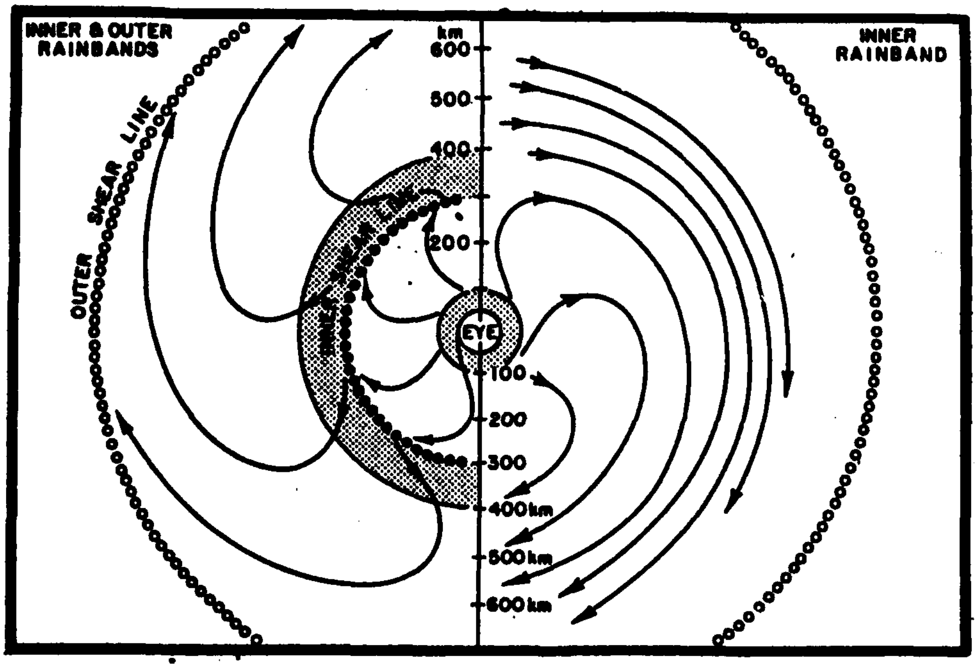


Figure 2-28. Tropical Cyclone High-Level Horizontal Cross-Section.

All three of the preceding figures have been modified to reflect the most recent tropical cyclone research findings. They show typical cloud distribution and high-level outflows for tropical storms. All tropical cyclones in the Caribbean have organized circulations, and are classified by maximum sustained wind speed (not gusts) into:

•*Tropical depressions*--Winds less than 34 knots.

•*Tropical storms*-- winds between 34 and 63 knots.

•*Hurricanes*-- winds above 64 knots.

Intense hurricanes sometimes include "concentric wall clouds"--a rare phenomenon that only occurs with central pressures below 950 mb, but most often below 920 mb. A circular outer convection ring forms at a radius of 50-75 miles (80-120 km) from the eye. For several days, these rings contract inward, progressively weakening the wall cloud structure. Eventually, this outer eye contracts enough to absorb the existing wall cloud. This phenomenon distorts "normal" hurricane wind and precipitation distribution. "Inner eye" maximum winds are weaker than might be expected; winds around the "outer eye" increase in intensity well beyond that which might be expected so far from the center. Winds *between* the two wall clouds are lighter--often remarkably so--than forecast. Precipitation distribution between the two wall clouds is similarly modified. The left sides of Figures 2-26 amd 2-28 show these concentric bands; the right sides show the more common and conventional single band at the eye. Normally, only hurricanes with long tracks over the Caribbean reach intensities required to form concentric wall clouds. "Allen" and "Gilbert" showed such behavior in their most intense stages. Although "Gloria" started to form concentric rings, she was not strong enough to complete them. There is some evidence that "Joan" had at least an incipient second wall cloud. These features are often obscured by cirrus and therefore hard to identify. Microwave satellite sounders, however, offer the possibility of spotting them by using sea surface wind patterns.

Storm frequencies and mean tracks are discussed further in other sections of this study.

POLAR SURGES. Most temperate zone and tropical meteorologists agree that classical Norwegian air mass and frontal theories don't apply in the tropics. Meteorologists at places where, for example, the Monsoon Trough is called the "intertropical front" or the "front intertropicale" (ITF or FIT) are merely reflecting long-established local convention. In certain areas of the world, however, polar air *does* penetrate deeply into the tropics. Such is the case in both North and South America. Details are provided in subsequent regional sections, but some polar surge generalities follow:

Surges from the North. In Central America and the Caribbean, cold fronts repeatedly enter the region from North America in fall, winter, and spring (a summer cold front might rarely reach the northern Gulf of Mexico in summer). Cold air is channeled by the Rocky Mountains, which run intact to as far south as the Isthmus of Tenhuantepec and with only a few low gaps as far as southern Nicaragua. The cold air modifies rapidly over the Gulf of Mexico and the Caribbean.

Most meteorologists in the U.S. believe that frontal characteristics are rarely found south of an east-west line drawn through Yucatan and the northern Antilles. However, Central American meteorologists insist that small but measurable air mass contrasts can be found in the lower 10,000 feet (3,050 meters), at least from December through March. Details aside, it is beyond question that polar shear lines reach deep into Central America and the Caribbean. In extreme cases they reach the Caribbean coast of Colombia and Venezuela. The northerly and northeasterly flow behind these shear lines gives considerable convective activity over any mountain range oriented even roughly east-west. Satellite imagery is the preferred--and often the only--means of tracking such surges once they enter the Caribbean Sea. Figure 2-29 shows such a surge--very strong--reaching deep into the Caribbean Basin.

Surges from the South. South America, because of channeling by the Andes and general downslope flow from extreme southern Brazil into the Amazon Basin, sees repeated outbreaks of sub-Antarctic air into the southern Amazon Basin during July, August, and September. Strong polar outbreaks reach all the way to the Equator; a few have been tracked as far north as southeastern Colombia, southern Venezuela, and the southern Guianas. There are at least two documented cases of southern hemisphere polar surges that reached the southern Caribbean. Northward surges are best followed by satellite imagery. Convection in the Amazon Basin is suppressed in the "cold" air behind the surge line; it is greatly enhanced in the Guyana Highlands and, in rare cases, as far north as the south side of the eastern Andean range along the Venezuelan coast. Figure 2-30, taken from Parmenter, shows an extreme case of a southern hemisphere surge.

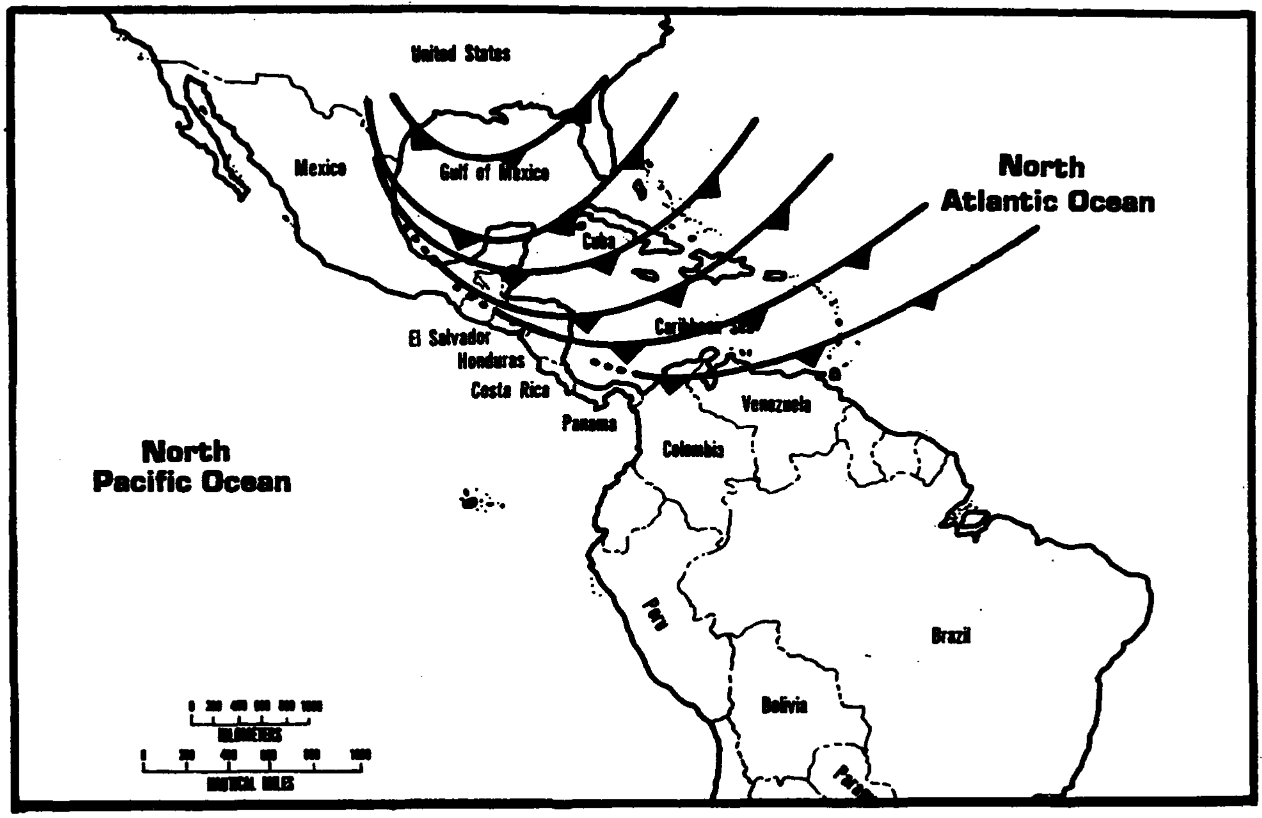


Figure 2-29. Northern Hemisphere Polar Surge.

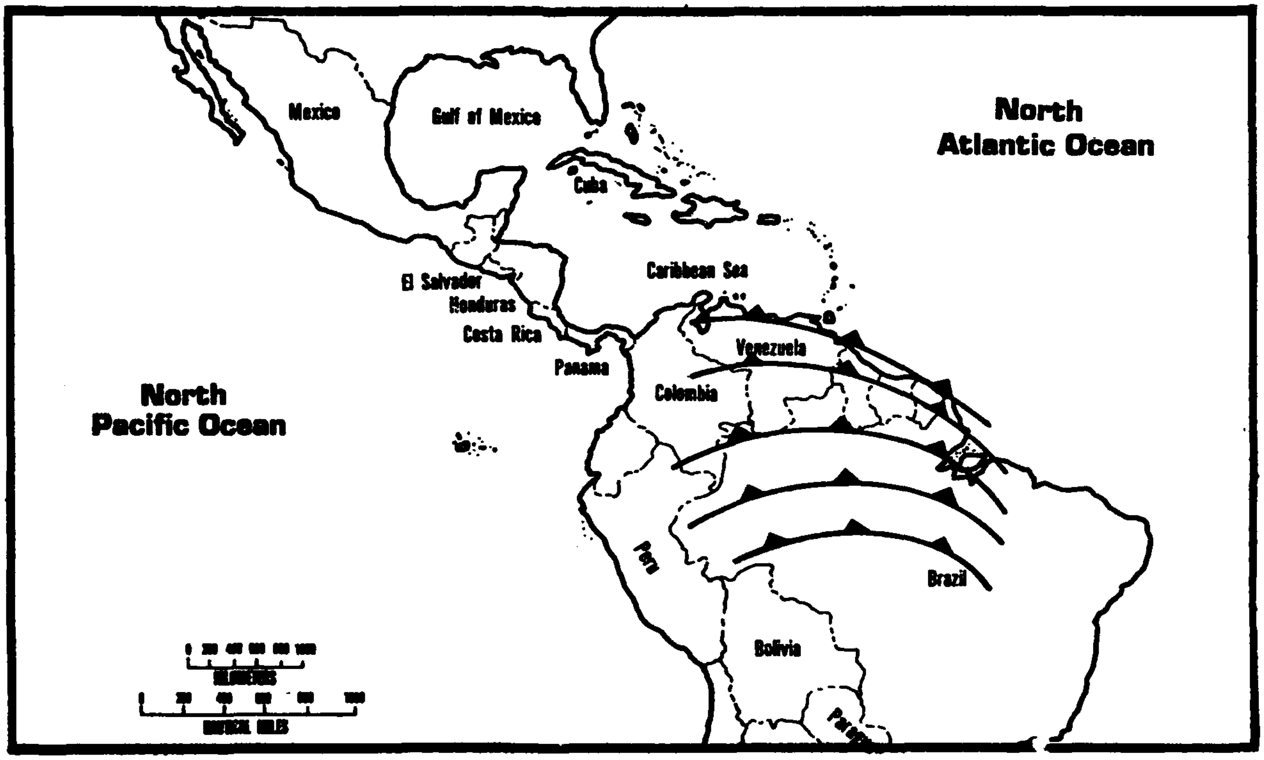


Figure 2-30. Southern Hemisphere Polar Surge.

LAND-SEA BREEZES. Coasts oriented perpendicular to the prevailing winds, as are the Atlantic and Pacific Coasts of Central and South America, are a primary cause of enhanced convection lines. This is particularly true where the coast is immediately backed by mountains. Two particular situations are important: In the first case, the prevailing trades are onshore. A strong land breeze forms in the early morning hours and opposes the prevailing trades. Shortly after local sunrise, a line of heavy cumulus forms 10 to 20 miles (16 to 32 kilometers) offshore. By mid-morning, the collapse of the land breeze allows this line to move onshore. The combination of the trades and sea breezes provide highly favorable conditions for movement well inland. Depth of penetration depends on the terrain; in the case of the Amazon Basin, it may be several hundred miles. Along the Pacific Central and South American coast, during those periods when the Equatorial Westerlies reach the coast, a similar phenomena occurs. Figure 2-31 shows this process at work.

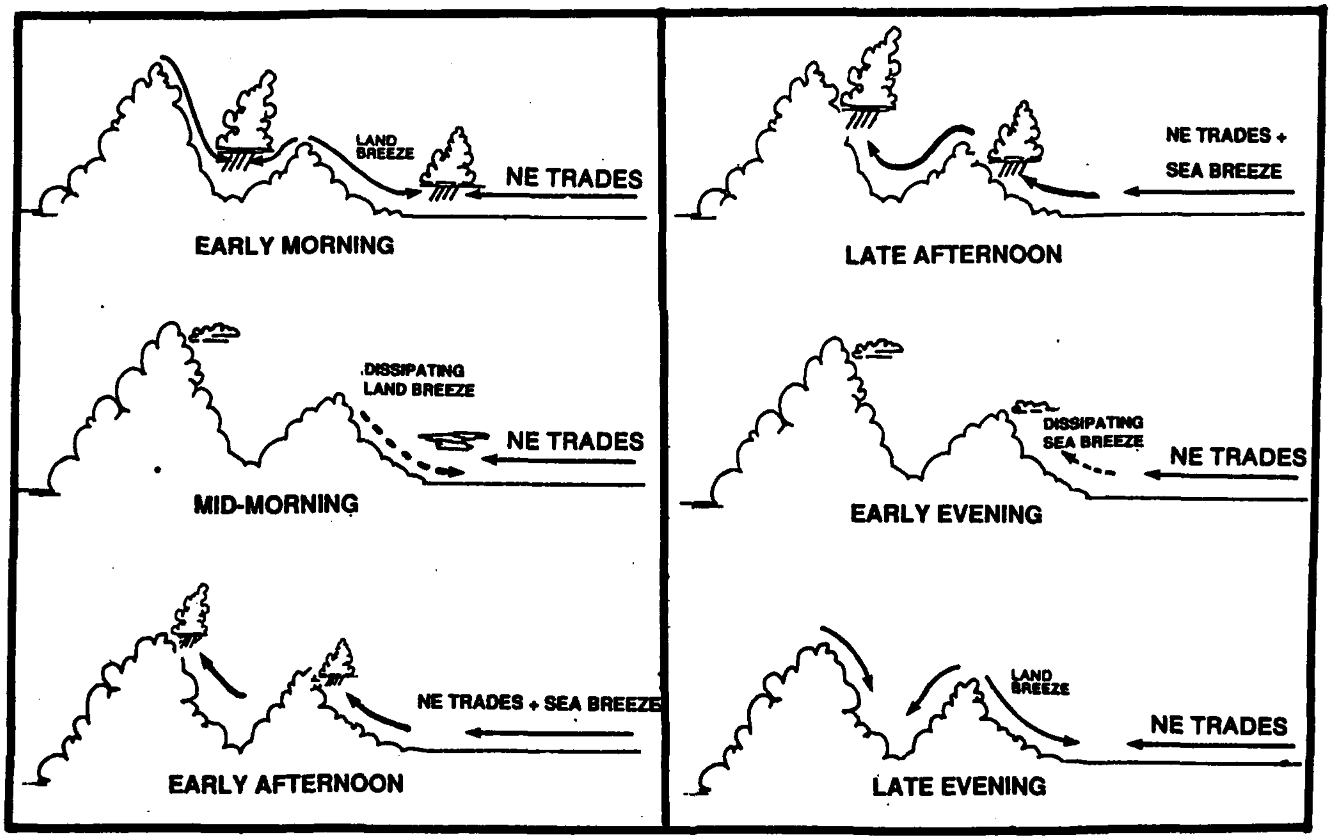


Figure 2-31. Land/Sea Breeze, *On-Shore* Gradient Winds.

In the second case, the prevailing trades are *offshore*. A typical example is that of the Pacific Central American coast during the wet season when the northeasterly trades are weak enough to allow convection to move onshore with the sea breeze. The sequence of events is similar to that with onshore trade flow; this time, however, the convection line rarely penetrates more than 10 miles inland. Exact "contra-trade" movement is a function of trade wind and opposing sea breeze strengths. This process is illustrated in Figure 2-32.

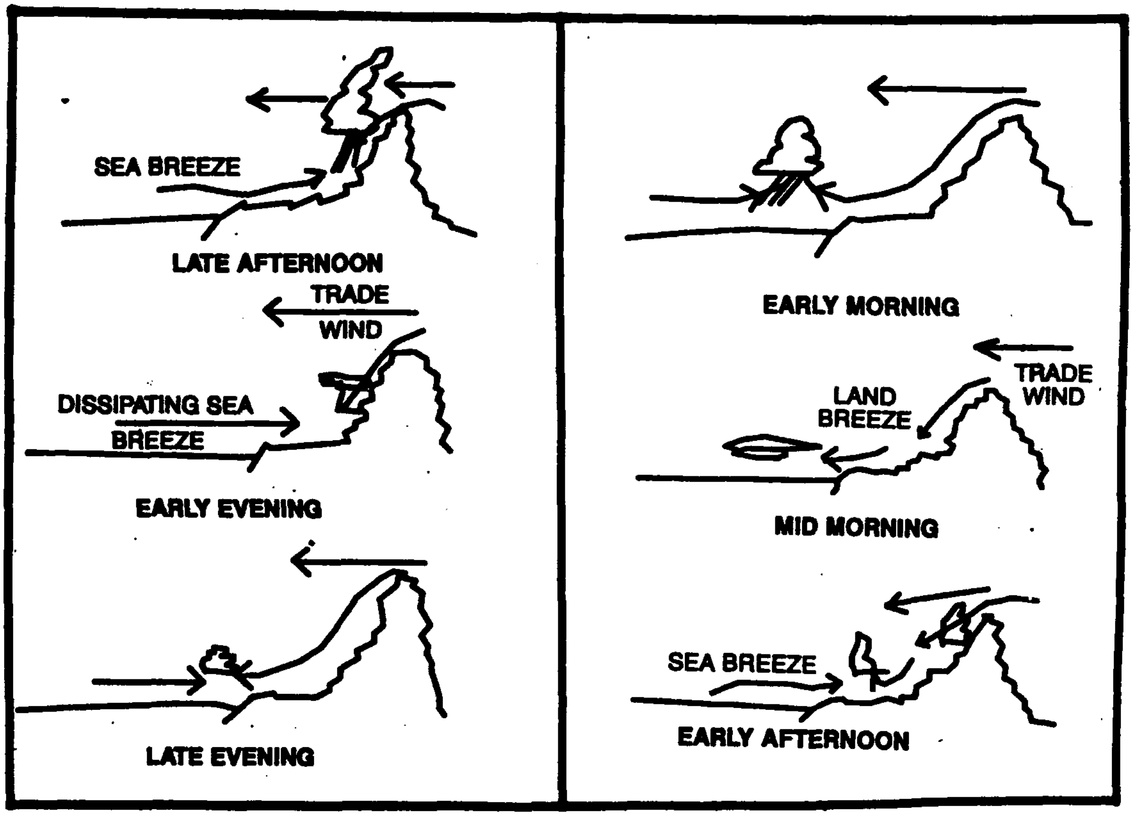


Figure 2-32. Land/Sea Breeze, *Off-Shore* Gradient Winds.

A special case of land-sea breeze convection occurs over peninsulas or relatively narrow land masses--such as Costa Rica and Panama--during periods of weak gradient flow. Here, sea breezes from opposite coasts meet over the central ridge line. The result is a late morning through early evening "standing wall of convection" over the ridge crest. Figure 2-33 shows how these convective lines form.

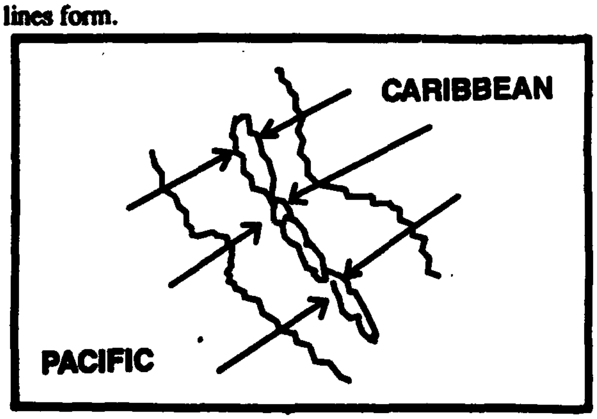


Figure 2-33. "Standing Wall of Convection."

LAND-LAKE BREEZES. In the absence of trade winds and mountain valley breezes, late night sees convergence and heavy cumuliform buildups in the centers of large lakes--Maracaibo in Venezuela and Nicaragua and Managua in Nicaragua, for example. Late afternoons would see virtually a cloud-free lake surrounded by a ring of heavy convection some 10 to 20 miles (16 to 32 kilometers) inland from the shore. The prevailing trades, however, tend to deform this effect into a bow shape with the end of the bow anchored along the mountains on either side of the lake. The bow reverses from night to afternoon, with the night apex being further upwind and the afternoon apex further downwind. This effect combines with mountain-valley breezes to produce the final shape and location of the convergence line. Heavy cumulus dissipates in early evening; if the trades are weak enough, land breezes converge in the middle of lake to form isolated heavy cumulus during early morning hours; they dissipate shortly after dawn. Figures 2-34 and 2-35 show *simple* and *complex* land-lake breeze regimes, respectively.

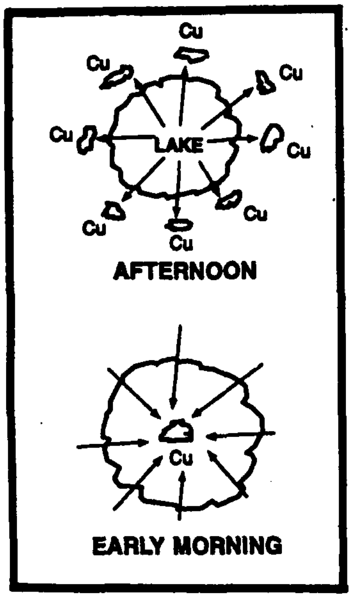


Figure 2-34. Simple Land-Lake Breeze.

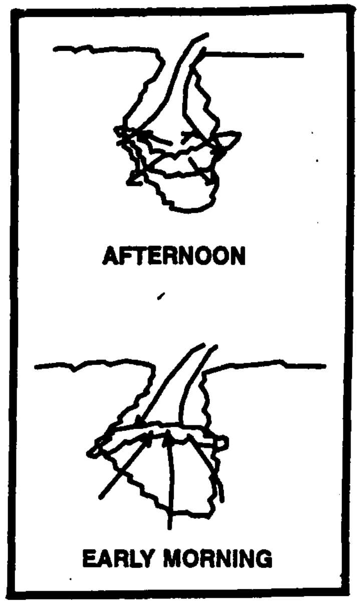


Figure 2-35. Complex Land-Lake Breeze.

MESOSCALE CONVECTIVE COMPLEXES. Satellite imagery shows heavy convective clusters in the interior of South America during the wet season. These are strikingly similar to the mesoscale convective cloud clusters (MCCs) found in the United States and, much like United States MCCs, these clusters last for 18 to 36 hours; they often reach the western Amazon basin. During May and June some have been observed to become stationary over the extreme western Amazon basin. They then apparently recurve eastward against the flow on the south (poleward) side of the monsoon trough. Such cases are both rare and controversial.

MOUNTAIN-VALLEY BREEZES may or may not affect local winds and weather, depending on mountain orientation and terrain complexity. Windward slopes of mountains see an enhancement of valley (upslope) breezes and drastic weakening--if not elimination--of mountain (downslope) breezes. These result in earlier formation of mountain cumulus, heavier precipitation along ridges, and increased chances of ground fog in valleys. Leeward ridge slopes see opposing effects. The strongest effects of classic mountain-valley breezes are normally found in the dry season when prevailing winds are lighter. Figure 2-36 illustrates this process.

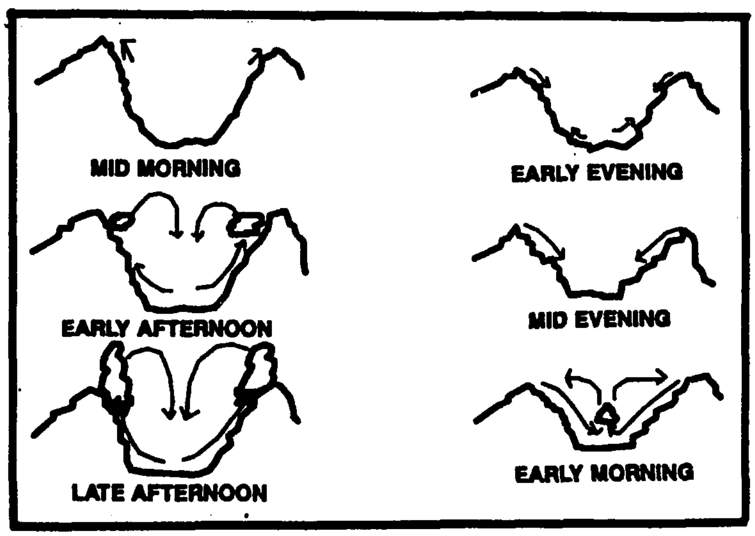


Figure 2-36. Simple Mountain-Valley Breeze.

A typical mountain-valley setup sees nocturnal fog and low stratus forming in valleys before dawn and dissipating by 0900 LST. By 1100 LST, heavy cumulus has begun to form along the surrounding ridge crests. By early afternoon, there are rainshowers or thundershowers over the mountains. When mountains are high enough--as in the case of the higher Andean ranges--snow or hail showers occur. If the mountain- top synoptic scale winds are strong enough, the showers or thundershowers move off the ridges and drift downstream over valleys. Convection dies out shortly after sunset; by mid- evening, skies are clear.

Variations on the simple mountain-valley breeze theme abound. Deep mountain canyons often see much warmer temperatures (many canyon bottoms are semi-arid) due to adiabatic compression of night mountain winds. Wide mountain valleys see afternoon convection cells spaced across the valley. Locations in or near the intersection of two or more mountain canyons/valleys see a complex combination of airflows that defy description.

Chapter 3

CENTRAL AMERICA

This chapter describes the situation and relief, major climatic controls, geography, and general weather of Central America, which is politically divided into seven countries and, for this study, a small part of Mexico. From north to south (with political abbreviations), the seven countries are: Belize (BH), Guatemala (GT), El Salvador (ES), Honduras (HO), Nicaragua (NK), Costa Rica (CS) and Panama. For this study, however, the Central American land mass has been divided into six regions selected on the basis of their topographic and climatological similarities. Those six regions, each of which will be discussed in this chapter, are shown in Figure 3-1, overleaf.

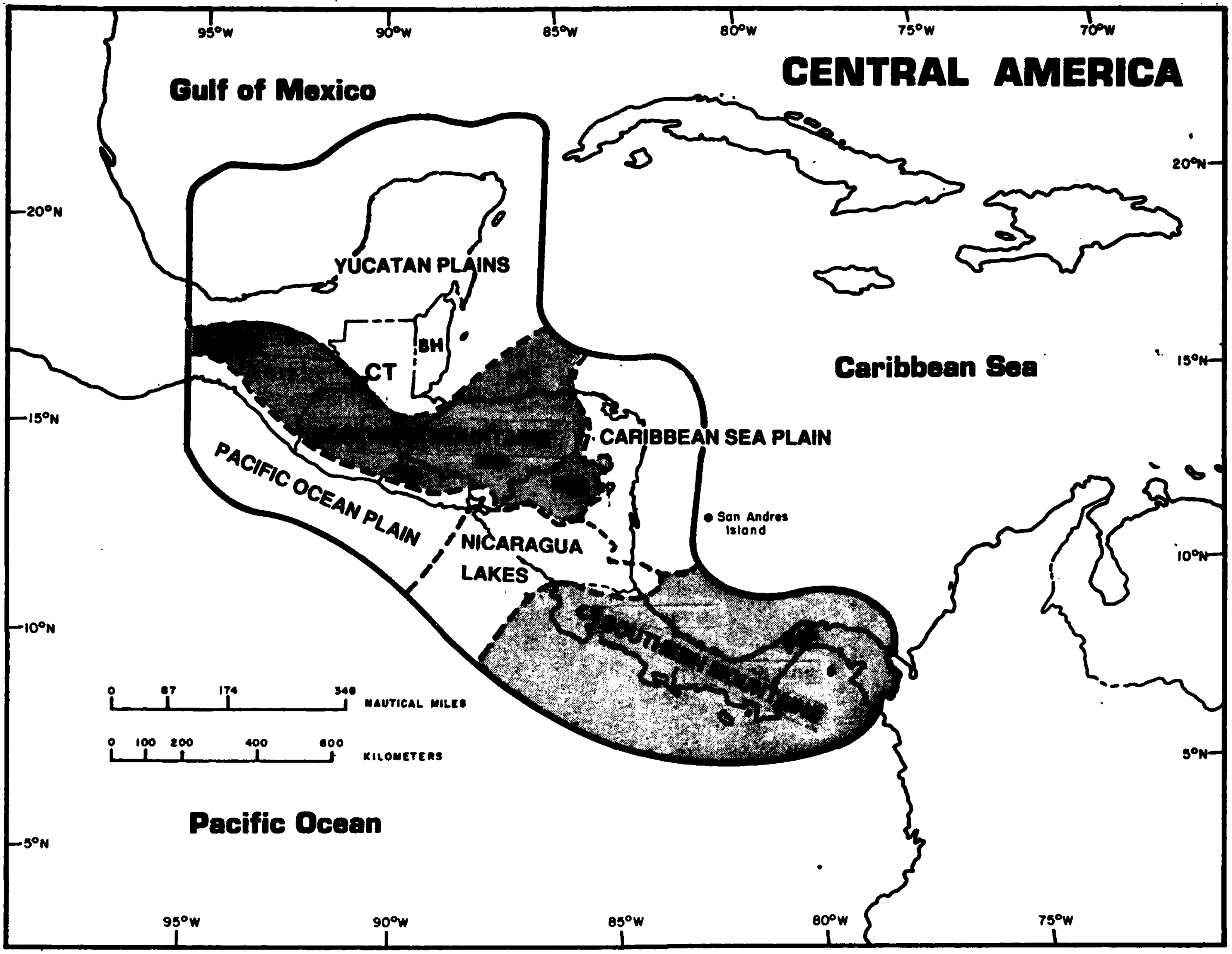


Figure 3-1. Central America, showing political and climatological divisions.

CENTRAL AMERICA

SITUATION AND RELIEF. Central America, as geographically defined in this study and as shown in Figure 3-1, opposite, is a ruggedly mountainous region that stretches more than 1,300 miles from the Isthmus of Tehuantepec and the Yucatan Peninsula in the north to the Panama-Colombia border in the south. It is about 32 miles (60 km) wide at its narrowest point across the Isthmus of Panama. Its widest point (513 miles--950 km) is from the northern tip of the Yucatan Peninsula to the Pacific Coast of Guatemala. Central America is bounded on the north by the Bay of Campeche and the Gulf of Mexico, to the south by the North Pacific Ocean, and to the east by the Caribbean Sea.

Two major geographic features affect Central American weather: First, mountain ranges (many with volcanic features) dominate the landscape of every Central American country. Many peaks reach from 10,000 to 15,000 feet (3,050 to 4,575 meters). All these ranges form barriers to the general atmospheric flow and affect every conceivable meteorological variable. Second, Central America is effectively a peninsula, situated so that there are large warm-water moisture sources on all sides. Large lakes and river systems act as secondary moisture sources.

For the purposes of this study, the Central American land mass has been divided into six regions selected on the basis of their topographic and climatological similarities. Those six regions, each of which is the subject of major discussion in this chapter, are shown in Figure 3-1. These regions are, in their order of appearance in this study: the Yucatan Plains, the Pacific Coastal Plain, the Caribbean Sea Plain, the Northern Mountains, the Nicaraguan Lakes, and the Southern Mountains.

MAJOR CLIMATIC CONTROLS. Central America is dominated by four major features:

The Monsoon Trough, representing the zone of convergent surface winds, produces extensive areas of heavy convection. The semipermanent nature of this convergence zone distributes rainfall in the form of thunderstorms over Central America during northern hemisphere summer and fall. The Trough oscillates seasonally from 2° N to 17° N, responding to increases in the magnitude and frequency of equatorial westerlies off the Pacific.

The Northeasterly Trades, generated by the North Atlantic High, bring warm Caribbean moisture into the region; seasonal variations in northeasterly flow across Central America are shown in Figures 3-2a-b. In January, as shown in 3-2a, the mountainous interior acts as an effective barrier to the northeasterly flow of moisture, and all the moisture off the Caribbean remains east of about 85 degrees. But in July, as shown in 3-2b, deeper flow penetrates all the way to the Pacific.

The Trade Wind Inversion controls the length and extent of the Central American dry season; this phenomenon (exclusive to winter) suppresses convection. The North Atlantic High produces semipermanent subsidence aloft with base heights varying between 6,000 and 9,000 feet (1,830 to 2,745 meters). The inversion base is not uniformly distributed over the region, but generally slopes upward from north to south. Lowest heights are observed during March and April, coinciding with the driest periods in the study area.

Tropical Storms and Hurricanes are wet season (June to November) phenomena. They typically originate as easterly wave impulses off the west coast of Africa and drift westward in the northeast trade wind circulation. There is severe wind damage and flooding wherever these storms make landfall. Figure 3-3 shows tropical storm source regions for each month of the Central American wet season.

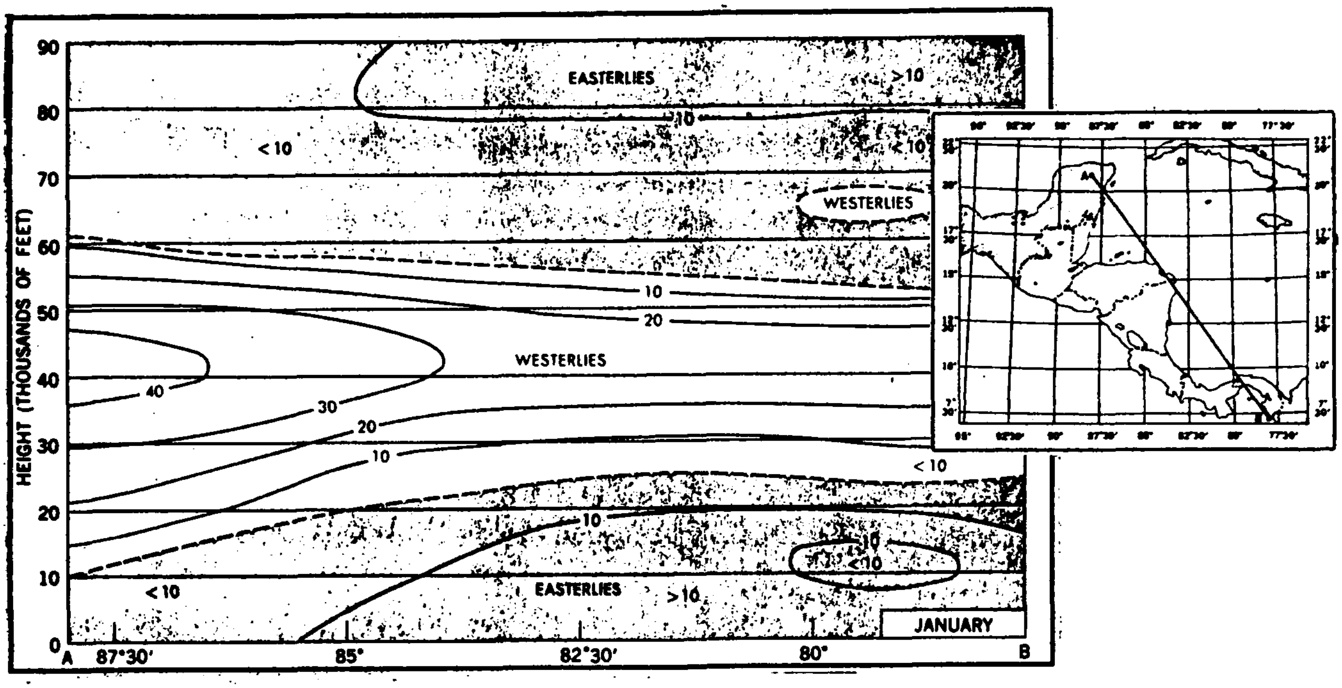


Figure 3-2a. Mean January (Dry Season) Vertical Wind Profile. Northeasterly flow weakens east of 85°N. The inset in both figures is a look-down view that shows how the large-scale topographic barrier inhibits moisture flow into western Central America.

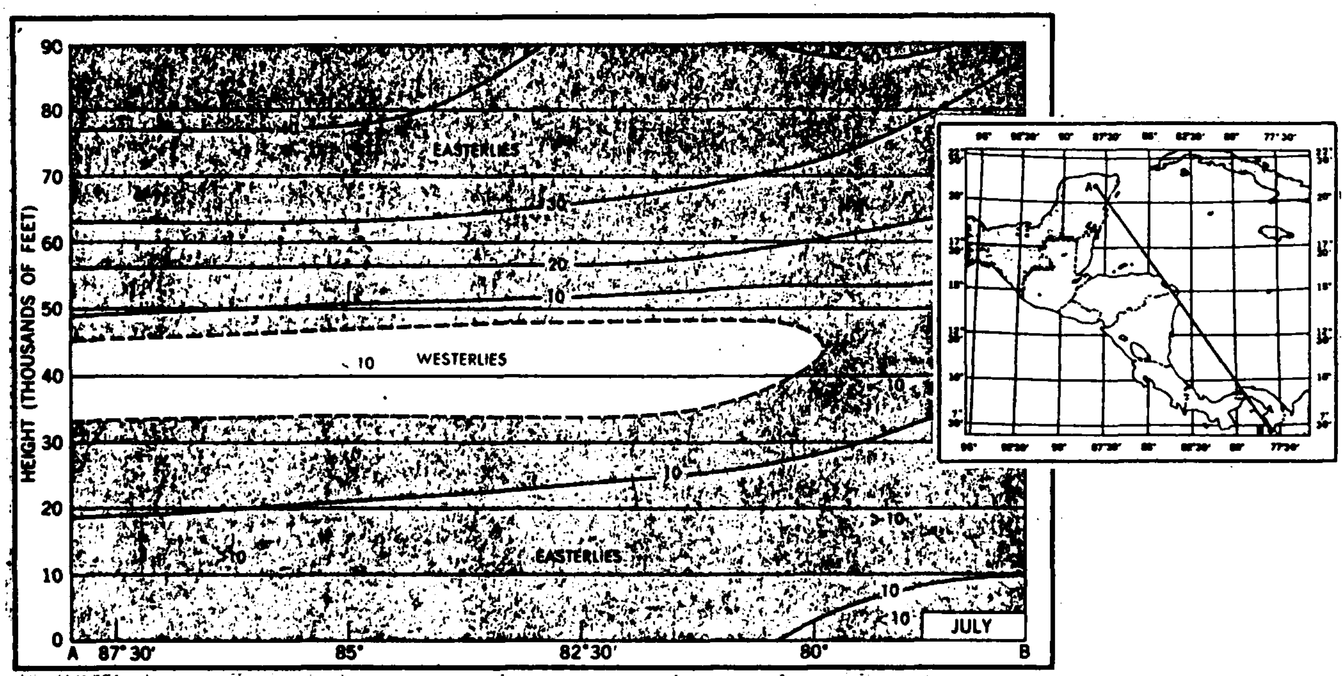


Figure 3-2b. Mean July (Wet Season) Vertical Wind Profile. Deep northeasterly flow penetrates into the Pacific. Strong flow (greater than 10 knots) is present to 20,000 feet MSL (6,100 meters).

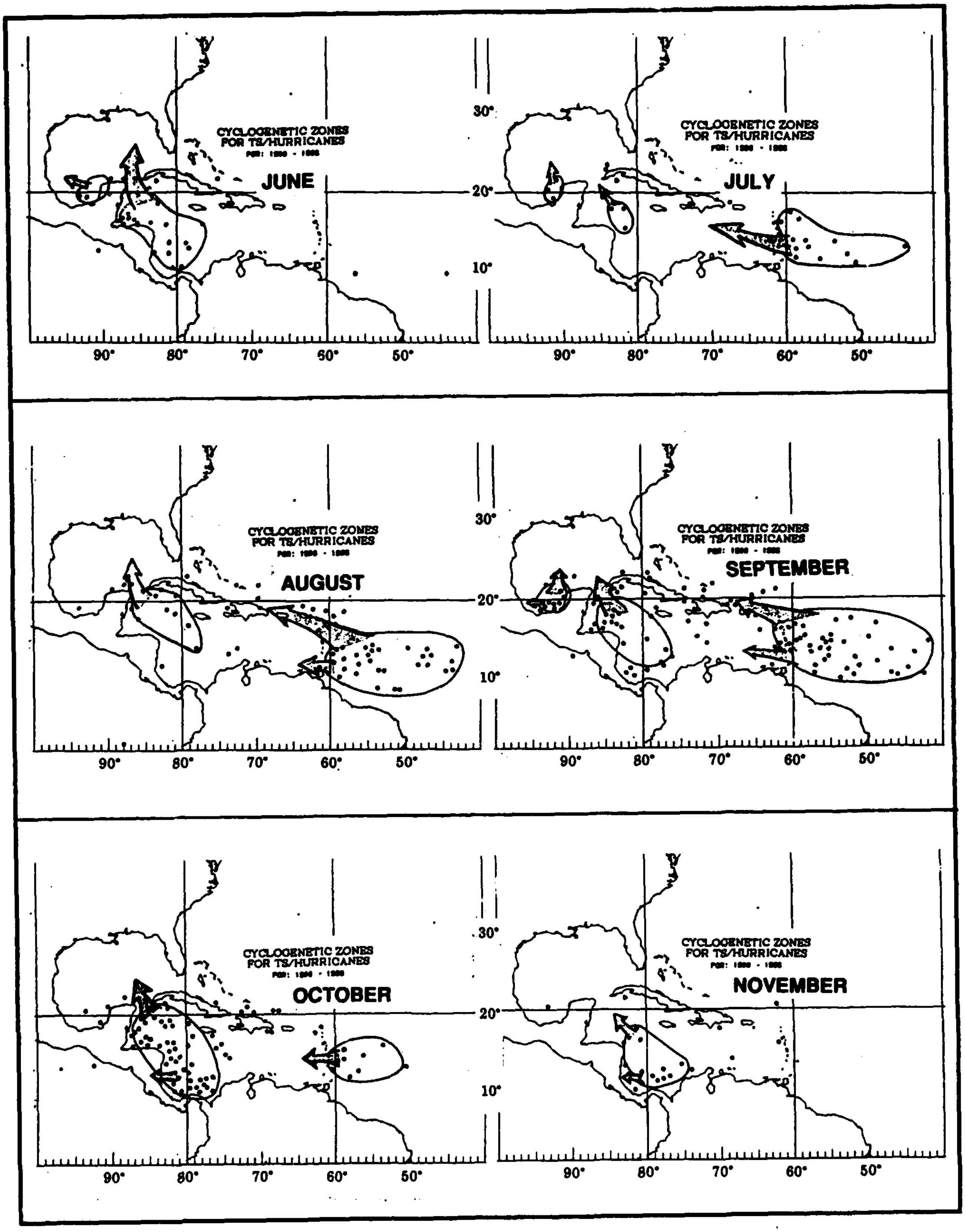
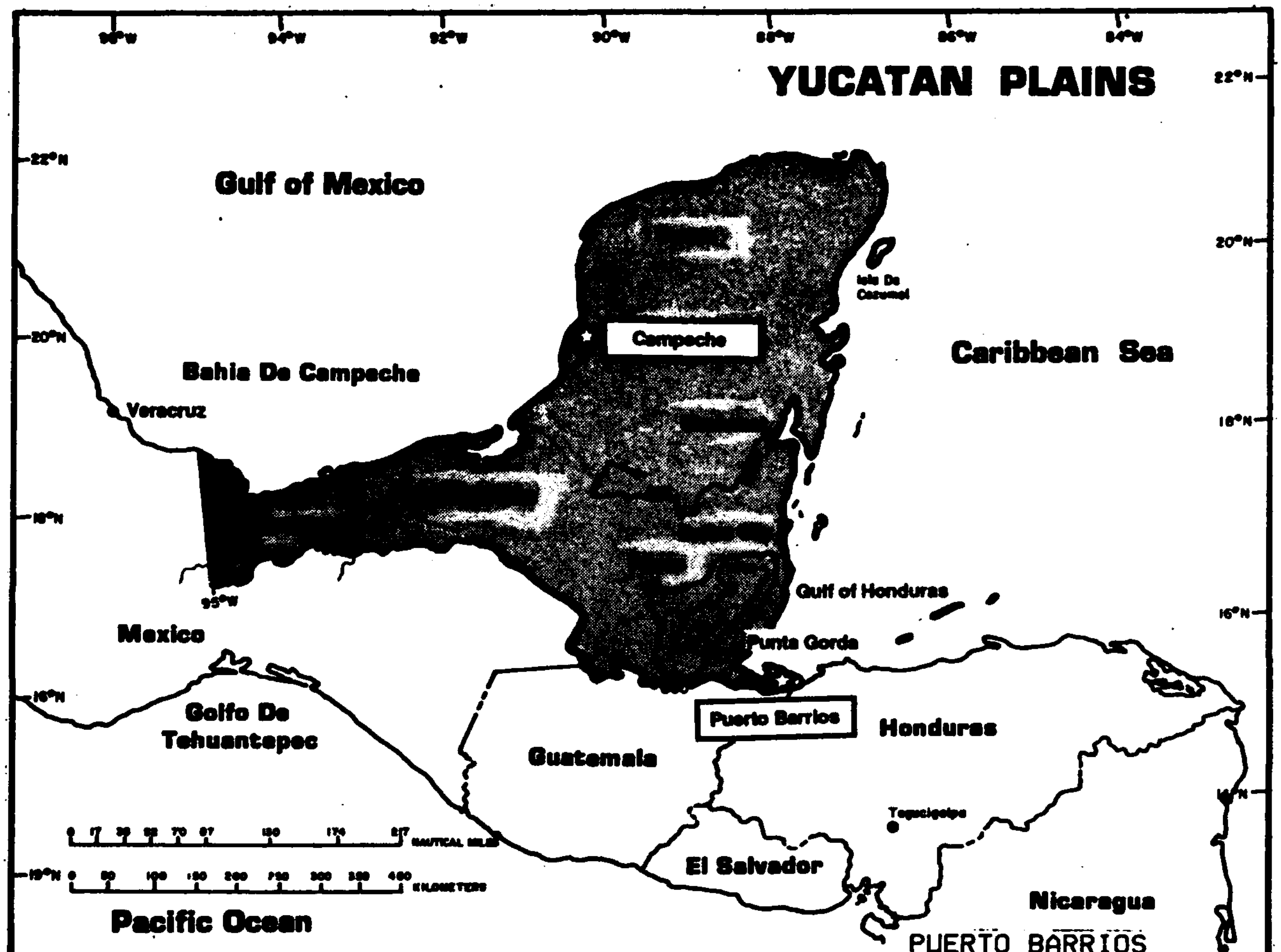


Figure 3-3. Tropical Storm Source Regions, June-November.

3.1 THE YUCATAN PLAINS



CAMPECHE MEXICO

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	92	72	49	.8	77	67	0	2
FEB	94	73	50	.4	78	67	0	1.1
MAR	99	76	54	.7	85	72	0	1.3
APR	100	81	58	.4	87	74	1	.9
MAY	103	83	65	2.9	90	76	4	5.8
JUN	100	81	70	7.8	87	77	6	18.7
JUL	97	80	70	8.1	88	76	7	10.9
AUG	95	80	68	7.6	88	76	7	12
SEP	94	80	70	8.9	88	75	6	13
OCT	92	78	63	4.4	84	74	3	4.7
NOV	90	75	53	2	80	71	1	3.7
DEC	90	73	50	.8	78	68	0	4.6

PUERTO BARRIOS GUATEMALA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	97	78	60	7.1	84	72	1	6.8
FEB	100	79	56	4.2	86	71	1	6.6
MAR	109	83	63	3	91	74	1	10.1
APR	110	86	66	4.1	93	77	3	4.7
MAY	108	86	68	7.8	94	78	9	3.6
JUN	107	86	72	10.8	93	79	19	5.5
JUL	102	85	74	16.7	91	79	23	4.9
AUG	100	85	75	12.1	92	79	23	6.2
SEP	104	85	72	11.5	92	78	20	6.6
OCT	100	83	66	14.6	88	76	10	6.2
NOV	96	80	62	10.6	85	74	4	7.8
DEC	96	78	60	9.2	84	73	3	11.2

Figure 3-4. The Yucatan Plains. This region comprises the entire Yucatan Peninsula south to the Altos Cuohumantes (Cuohumantes Highlands) and the Sierra de las Minas (Minas Mountains) in central Guatemala. The region includes the northern extension of Guatemala and the country of Belize. The southwestern boundary runs along the base of the Chiapas Plateau westward into the Isthmus of Tihuantepec with an arbitrary demarcation at the 500-foot (150-meter) contour line. Monthly climatology summaries for Campeche, Mexico, and Puerto Barrios, Guatemala, are inset.

YUCATAN PLAINS GEOGRAPHY

The Yucatan Peninsula has long coastlines on the Bay of Campeche, the Gulf of Mexico, and the Caribbean Sea. In effect, it separates the Gulf of Mexico from the Caribbean. The Tabasco region on the northwest (or Bay of Campeche) coast has large river systems and many small lakes. Rivers of all sizes have created extensive marshlands on both sides of the peninsula. Terrain rises gradually inland from north to south, leveling off to a plateau that stretches from the south-central part of the peninsula into central Guatemala.

Large bays pockmark both coasts of the Yucatan Plains region; the two largest are the Bay of the Ascension and the Bay of Chetumal. The Bay of Campeche (actually the southward extension of the Gulf of Mexico) dominates the northwest coast. There is a smaller bay at Isla del Carmen.

Extensive river systems cover the plain. There are numerous small lakes and lagoons, especially in the Plains of Campeche and Tabasco to the northwest. Here, innumerable small lakes are connected by large rivers such as the San Antonio, the Grijalva, the Uspanapa, and the Coatzacoalcos. The Chipas Mesa (Meseta de Chiapas) to the southwest is the source region for the hundreds of tributaries feeding these rivers. These meandering waterways have produced extensive marshlands along the southern coasts of Campeche Bay.

Rivers and marshlands are equally extensive on the Caribbean Coast. From the Bay of the Ascension southward to the Gulf of Honduras, the relatively flat terrain is interrupted only briefly by the Maya Mountains in southern Belize. The rivers in this area, while more numerous, are not nearly as large as their western counterparts. The Caribbean coastal elevation is less than 328 feet (100 meters) and is subject to local flooding after prolonged heavy rains

The inland region of the Yucatan consists of a plateau rising gently from the coastal plains into the foothills of central Guatemala. The combination of gradual slope, limestone soil, and frequently heavy rain encourage extensive marshlands in northern Guatemala, especially in the area north of Lake Peten Itza, at Flores.

Coastal swamps on the Yucatan rapidly give way to cropland and scattered forests inland. With increasing elevation, woodlands begin to predominate. These broadleaved evergreen forests yield to grasslands in southern Belize and central Guatemala at terrain heights over 1,000 feet (305 meters).

GENERAL WEATHER. Strong diurnal surface heating produces daily afternoon tradewind cumulus and isolated showers throughout the region. Heavier showers and thunderstorms typically develop within other synoptic disturbances. Easterly waves, hurricanes, polar surges, and tradewind surges in the Monsoon Trough will trigger larger scale convection (see Figure 3-5). The 300-millibar flow pattern usually sustains strong convection during the summer.

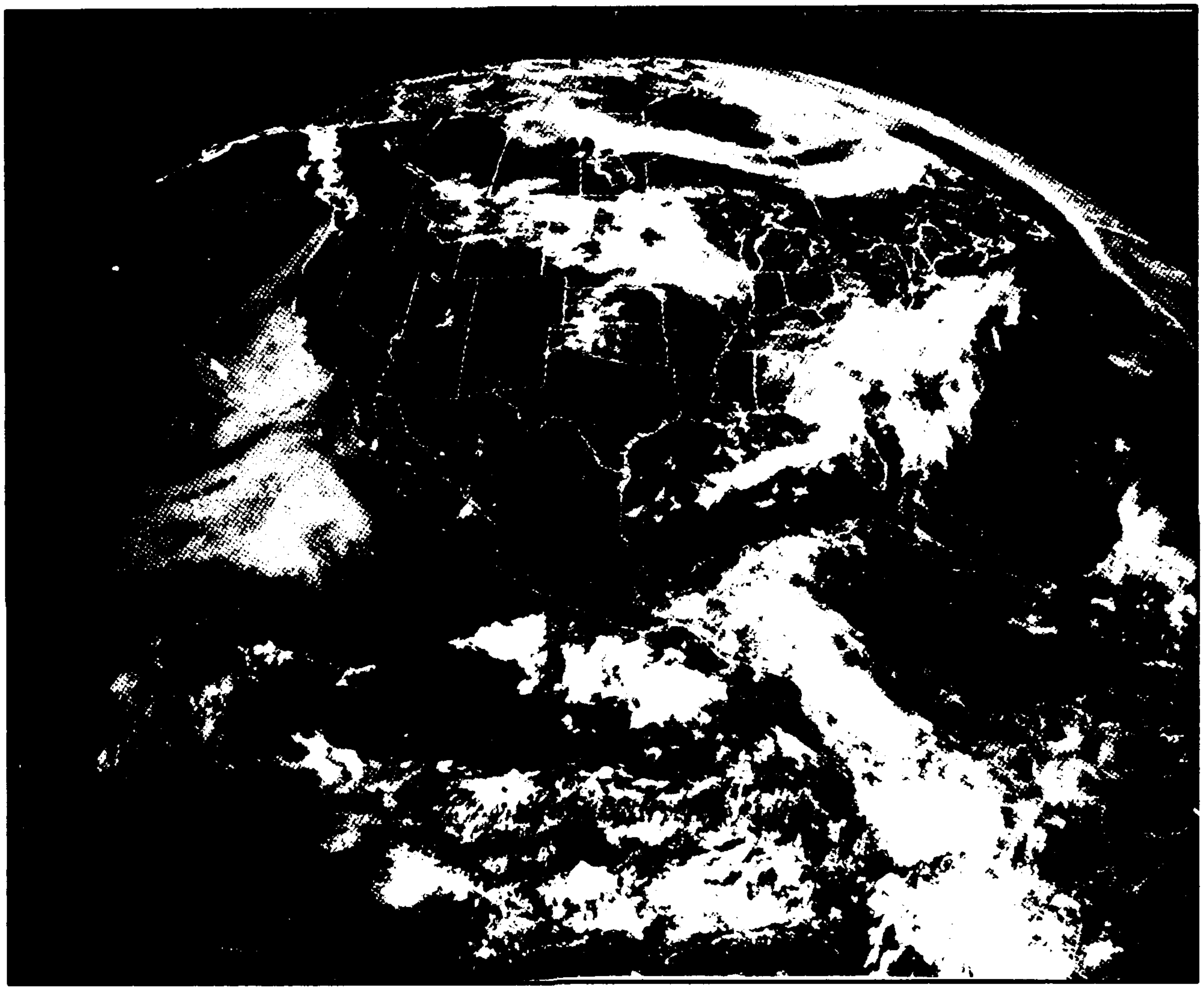


Figure 3-5. Typical Wet Season Weather Pattern. Good outflow at 300 millibars sustains heavy sea breeze convection throughout Central America, as shown in this 13 August 1986 satellite photo.

SKY COVER. Relative humidities during the wet season are extremely high at 70 to 87%. High dew point temperatures (69-74°/21-23°C) produce condensation at the 2,000- to 3,000-foot (610- to 915-meter) level during the day. Percent frequency of ceilings below 3,000 feet (915 meters) for all hours shows the increase in sea breeze trade wind cumulus along the lowlands near Chetumal, Mexico, during the summer. Figure 3-6 gives month-to-month comparisons of daytime ceiling frequency below 3,000 feet at Merida, Chetumal, and Puerto Barrios.

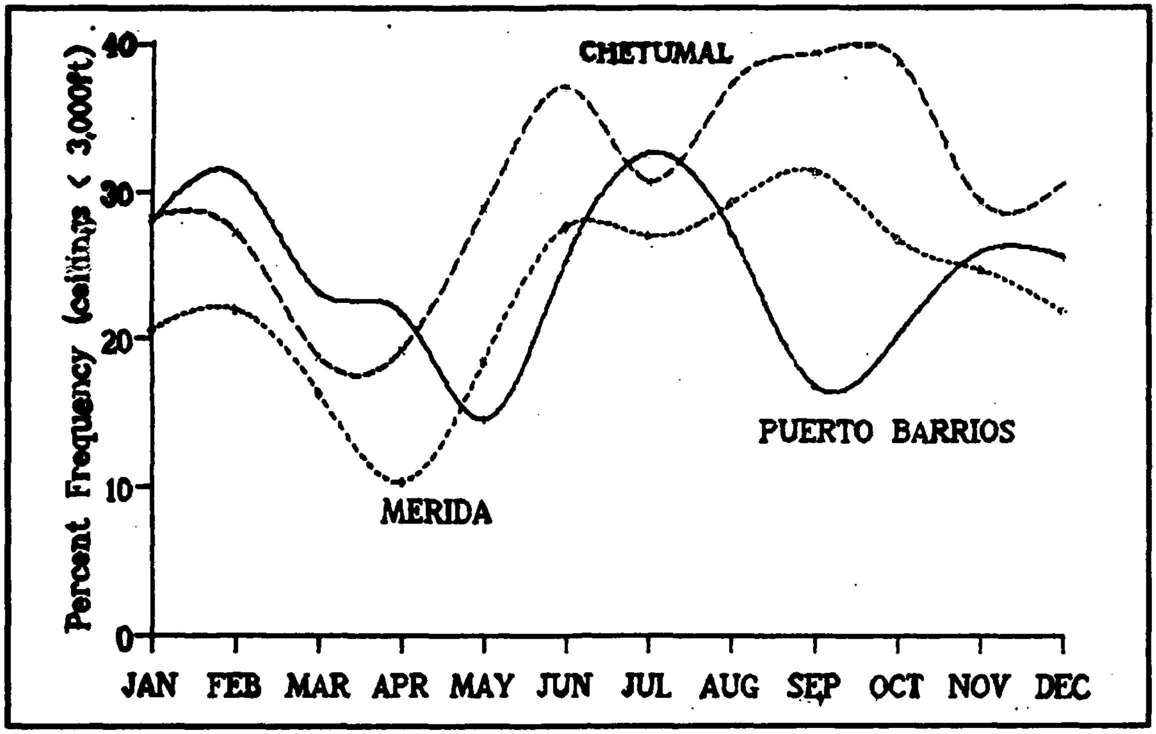


Figure 3-6. Percent Frequencies of Ceilings below 3,000 feet (All Hours).

Mean cloudiness (62-73%) varies little throughout the Yucatan except on the northern coast of the peninsula, where it averages 5-10% less. The differences are a function of cloud type; typically, cirrus associated with weak easterly waves and polar surges cause the slight difference. Often, cirrus covers the immediate coastline during weaker frontal passages, while low-level advection of stratus (with bases near 1,000 feet or 330 meters) is common with the more intense passages. Cloud cover along the Caribbean shores, on the other hand, consists of trade wind cumulus (with bases near 3,000 feet or 915 meters and tops reaching 20,000 feet or 6.2 km) moving inland over the southern plain. Orographic lifting produces slightly greater mean cloudiness. The frequency of ceilings below 1,000 feet (330 meters) increases after 1900 LST and lasts until 0600 LST because of slower diurnal wind velocities, lower air temperatures, and moisture convergence. In Puerto Barrios, ceilings less than 3,000 feet are most frequent (35-42 percent of the time) between 1900 and 0600 LST. Land breeze convergence over warm waters in the Gulf of Honduras increases the percent frequency of ceilings below 3,000 feet (915 meters) beginning in May through an August peak. This phenomenon is illustrated by the ceiling curve in Figure 3-7 for Puerto Barrios, Guatemala, between 1900 and 0600 LST.

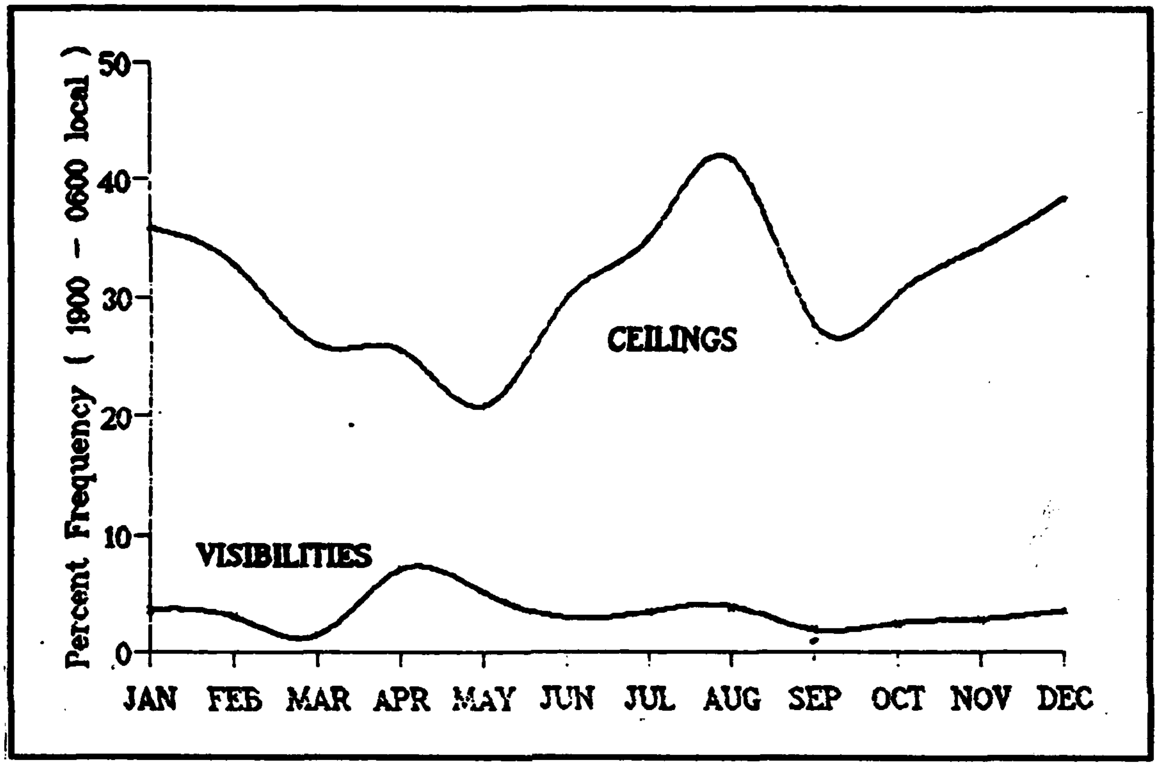


Figure 3-7. Percent Frequency of Ceiling/Visibility Below 3,000/3, Puerto Barrios, Guatemala, 1900-0600 LST.

WINDS. Northeast trade winds average 5-8 knots and affect the entire region during the summer. Daytime sea breezes rarely exceed 10 knots, but are stronger in May when intense surface heating creates a steeper pressure gradient along the sea breeze front. Winds at 20,000 feet (6,098 meters) become northeasterly in May at Merida, Vera Cruz, and Belize City. From June through September, winds at 30,000 feet (9,146 meters) show northerly outflow from the 300-mb anticyclone in all upper-air observations. See Figure 3-8 for month-to-month comparisons of wind direction at 5,000 feet at Merida, Belize City, and Vera Cruz. The trade wind flow on the northern tip of the Yucatan peninsula, for example, parallels the coast and is perpendicular to the sea breeze. The resulting wind vectors are divergent. Along the windward mountain slopes, breezes from the Caribbean and the Bay of Campeche produce daytime convergence lines, while westerly land breezes, accentuated by topography, funnel nocturnal low-level convergence into southern Belize. These convergent breezes produce annual precipitation amounts of more than 130 inches (3,302 mm). The persistence of easterlies is evident except at Vera Cruz in October; the reason: its proximity to migratory lows and mid-latitude westerlies.

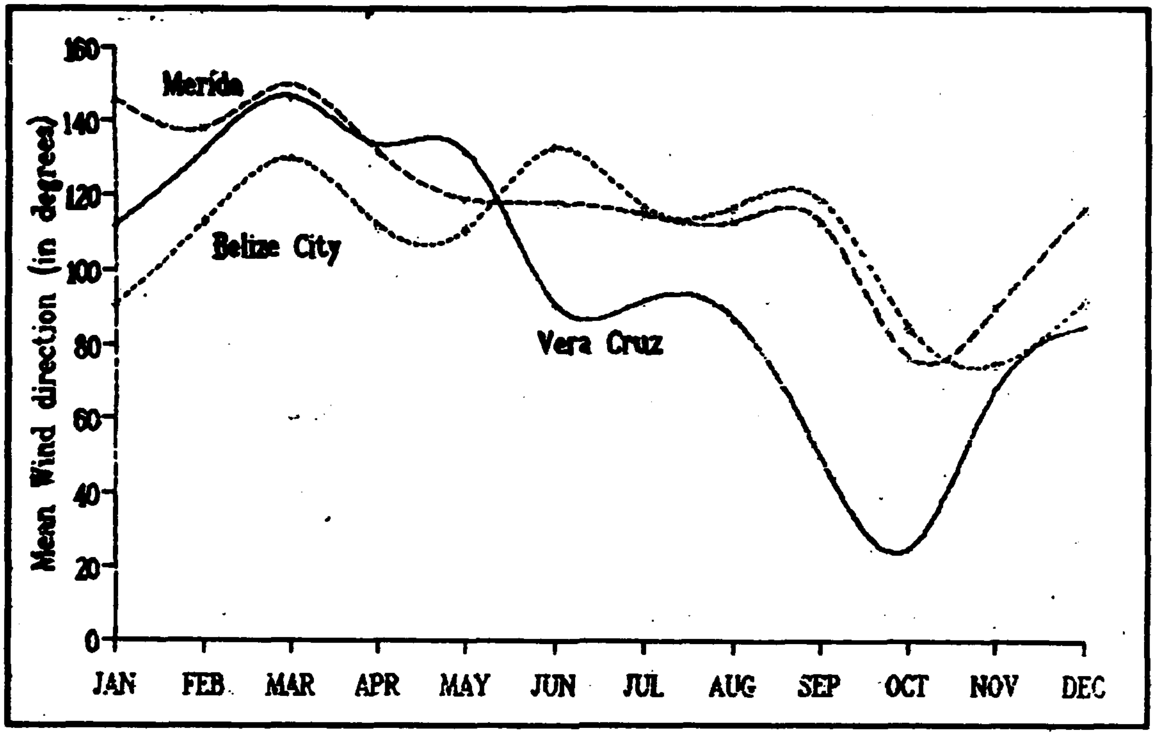


Figure 3-8. Mean Wind Direction for Three Locations on the Yucatan Plains. Vera Cruz actually lies to the west of the Yucatan Plains region. Even so, its upper-air observations are representative of conditions along the southern coast of the Bay of Campeche.

HURRICANES. The main effect of Central American hurricanes is concentrated near the coastal port of Belize City; most storms that affect the Yucatan make landfall within a 100-mile radius of this unfortunate community. Ceilings of 500 to 1,000 feet (150-330 meters) are common, and winds associated with individual spiral bands vary in strength and direction. Another similar disturbance, the Temporale, may occur during surges of the Monsoon Trough when low-level convergence stimulates the atmosphere in the Gulf of Honduras. Tropical depressions and sub-tropical cyclones that shear from descending mid-latitude fronts stagnate in relatively calm surroundings along the coastal edges of the western Caribbean. Monsoon Trough surges concentrate low-level convergence within the pre-existing region of instability. The conditions leading to the intensification of these cells are poorly understood. Unlike hurricanes, temporales are characterized by an "all-layer depression" (Hastenrath, 1985) maintained by large-scale low-level convergence (surges), convection, and upslope motion of moisture along topographic barriers. Further, the "temporale" (as the term is used here) is typically composed of stratiform cloudiness with virtually no wind or thunder, thus separating the phenomena from the "convective cloud cluster." However, intense rainfall of 1 to 2 inches (25-52 mm) an hour is not uncommon. Temporales are most frequent in September and October during the height of southwesterly flow from the Pacific.

THUNDERSTORMS. Although convective activity is at its peak during the wet season here, the annual number of thunderstorm days throughout the region is surprisingly low. Merida, on the northern edge of the plain, averages thunderstorms on 9 days a year, while Coatzacoalcos, Mexico, farther to the west along the Mexican coast, averages 33 days. The westward increase in storminess is related to topography and favorable coastal configurations that do not create low-level divergence. Belize City, on the Caribbean coast , has 52 days with thunderstorms during the wet season alone, with 11 of those days in August and 10 apiece in June and July. Orographic uplift increases the chance for severe thunderstorms; there may be small hail and damaging winds that reach 45 knots.

PRECIPITATION. Distributions vary widely (from 30 to 160 inches) throughout the region, but amounts generally decrease from southwest to northeast. In southern sections, easterly wave and Monsoon Trough instability combine to produce higher rainfall totals. The west coast of the Yucatan proper averages 30-50 inches a year, mostly from mid-latitude fronts and tropical depressions. Inside an imaginary triangle from Punta Gorda, Belize (16° 10' N, 88° 45' W), southward to Puerto Barrios, Guatemala (15° 43' N, 88° 35' W), and then west-northwestward into the northern Guatemalan plain and southern Mexico, rainfall is a product of convergence line convection of daytime onshore flow along the eastern edges of the Guatemalan mountain ranges. Along the northern Caribbean coast at the Yucatan coastal village of Chetumal (18° 30' N, 88° 18' W), trade wind flow reinforces the sea breeze, but lack of significant topography produces average annual precipitation of only 45 inches. On the northern Mexican coast, the rainfall totals decrease west to east, from 80 inches annually at Coatzacoalcos to 35 inches at Merida. Thunderstorms produce the greater percentage of daily rainfall amounts in summer, and paralleling easterly flow may produce localized offshore upwelling (cooler sea surface temperatures) which may contribute to a precipitation deficiency (and fewer thunderstorm days) near Merida.

TEMPERATURE. Average wet season highs are from 85 to 89°F (30-32°C) throughout the Yucatan; combined with high dew points, heat index values can be dangerously high. Absolute high temperatures at southern locations are generally in the upper 90s (36-37° C), while on the northern Mexican coast they run in the 103-106°F (40-41°C) range; Merida and Coatzacoalcos have both reached 106°F (41°C). Nights are mild and balmy; average temperatures, uniformly moderated by the Caribbean and the Gulf of Mexico, stay between 62 and 70°F (17-22°C).

GENERAL WEATHER. The most important feature that determines transition weather is the dramatic shift in mid- and upper-level flow from easterly to west-southwesterly. Deep polar troughs (over the western United States) and a strong subtropical jet (50-80 knots) allow modified polar air to descend into the region one to six times a month. These polar fronts frequently stall over the Yucatan, producing widely scattered showers and sometimes thundershowers.

SKY COVER. Mean sky cover during the transition decreases from 55 to 48 percent by the first of December. When northerly winds are predominant, stratus forms along the immediate coasts in response to warmer Gulf waters. Bases average from 1,000 to 1,500 feet (330-460 meters). On evenings after the passage of "Nortes" or fronts, calm wind conditions can result in shallow fog and haze just before sunrise. Typically, trade wind cumulus forms over the eastern half of the Yucatan Plains, often with tops near 8,000 feet (2,440 meters) but rarely above 12,000 feet (3,660 meters). Bases form at around 2,000-4,000 feet (610-1,220 meters). Cirrus often accompanies undisturbed weather conditions.

WINDS. In November, the passage of "Nortes" (or fronts) can produce instantaneous wind shifts to the north and northwest. Speeds can increase by 10-20 knots with peak gusts over 35 knots. Winds aloft (above 15,000 feet/4,575 meters) are westerly, averaging 20-30 knots and approaching 70 knots in the subtropical jet.

TEMPERATURES. Maximum temperatures are from 80 to 90°F (25-32°C). Minimum temperatures along the coast average 70-74°F (21-23°C). Extremes above 95°F (34°C) are rare.

PRECIPITATION. The drier conditions of winter are reflected in the increasing lack of storm development. Cold fronts account for 85 percent of dry season rainfall. Southern Belize and those areas of Guatemala that are on the Yucatan Plain still receive between 2 and 3 inches of precipitation by the end of the transition. The northern parts get 1 to 2 inches a month. Rare, heavy rainfall episodes are the products of tradewind surges in the Monsoon Trough. Figures 3-9a-e show one such episode from the initial 13 November 1979 surge through the storm's dissipation 4 days later.

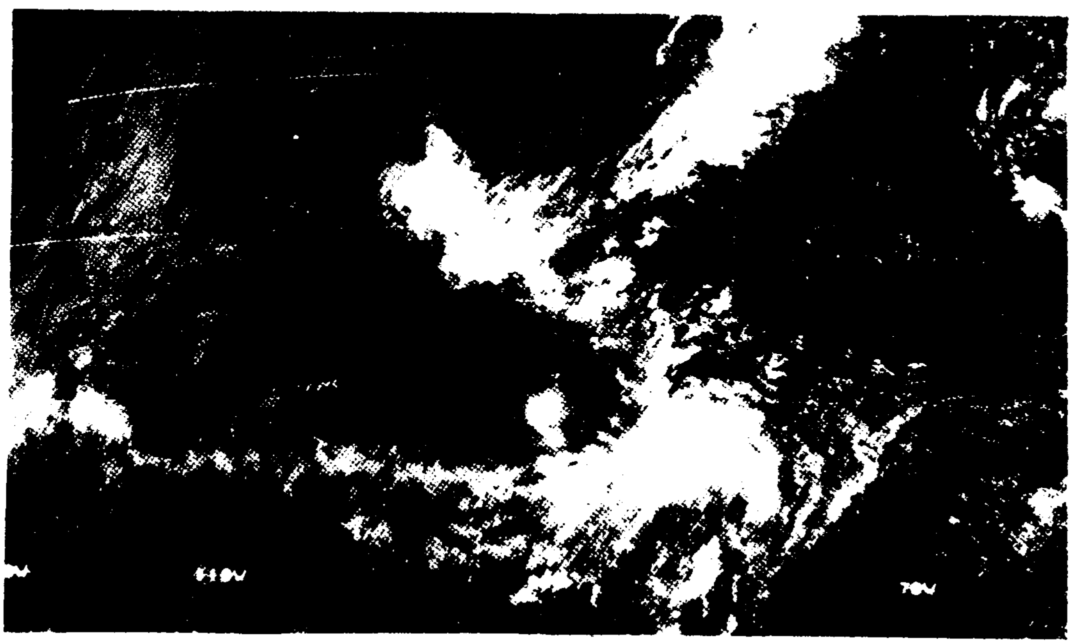


Figure 3-9a. The Initial Surge of the Monsoon Trough, 13 November 1979.

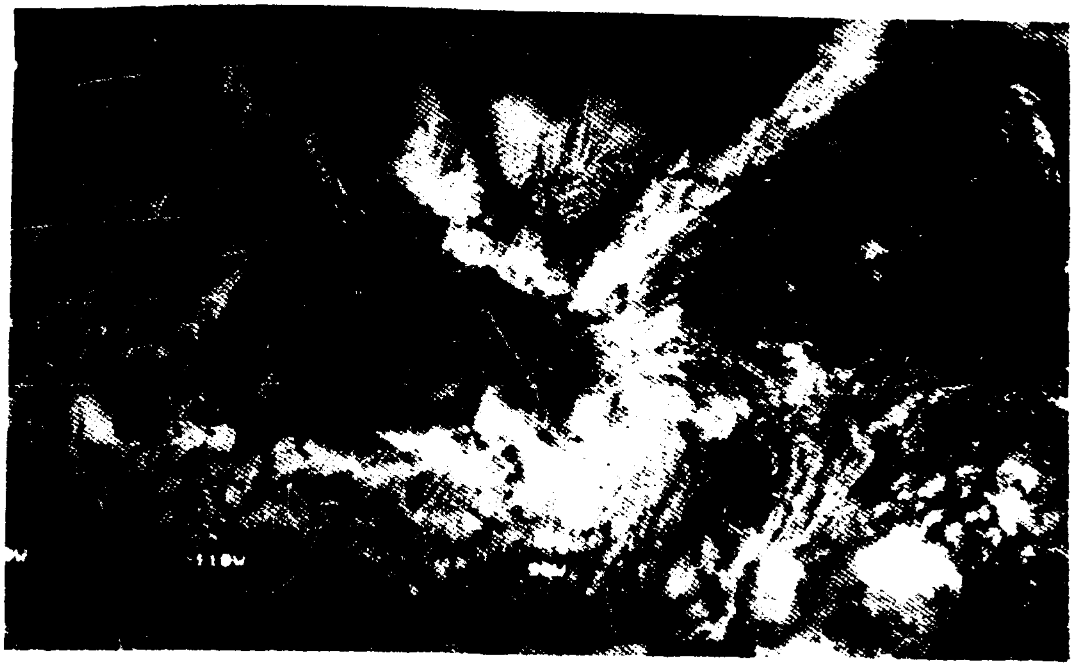


Figure 3-9b. Surge Interaction With Frontal Passage, 14 November 1979.

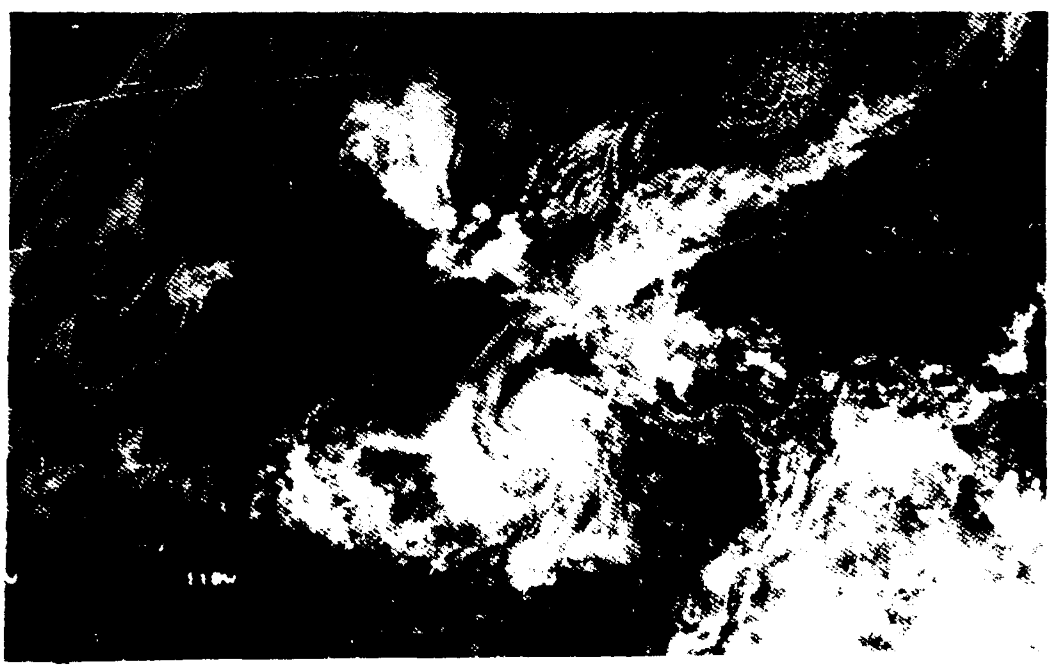


Figure 3-9c. Tropical Depression Formation, 15 November 1979.

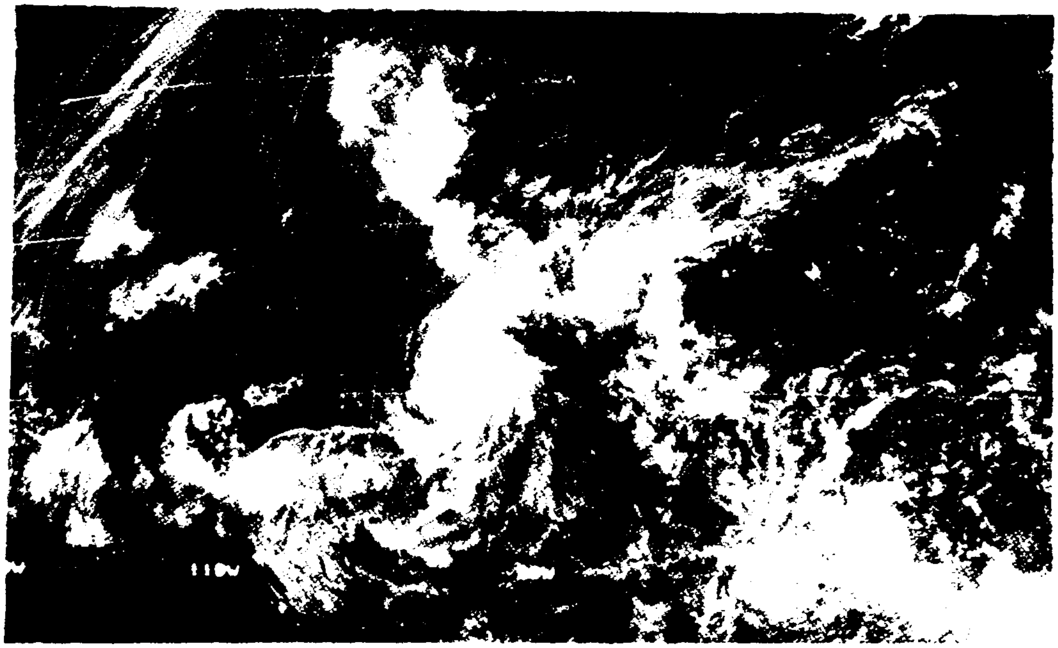


Figure 3-9d. Mature Tropical Storm, 16 November 1979.

Figure 3-9e. Dissipation Stage, 17 November 1979.

GENERAL WEATHER. Large-scale subsidence is the dominant dry season weather feature. The tradewind inversion is at 6,000 feet (1,830 meters), with a mean thickness of about 900 feet (275 meters). The inversion, along with the dry, anticyclonic flow aloft (WNW-ENE at 500 millibars) dampens large-scale diurnal convection. Conditions aloft confine the sea breeze circulation and associated tradewind cumulus to the immediate coastlines (5-20 NM inland). Nearly all dry season rainfall days (1 to 5 a month) occur during polar surges. However, showers are mostly scattered and rarely heavy. Figure 3-10 shows a typical late-winter frontal passage.

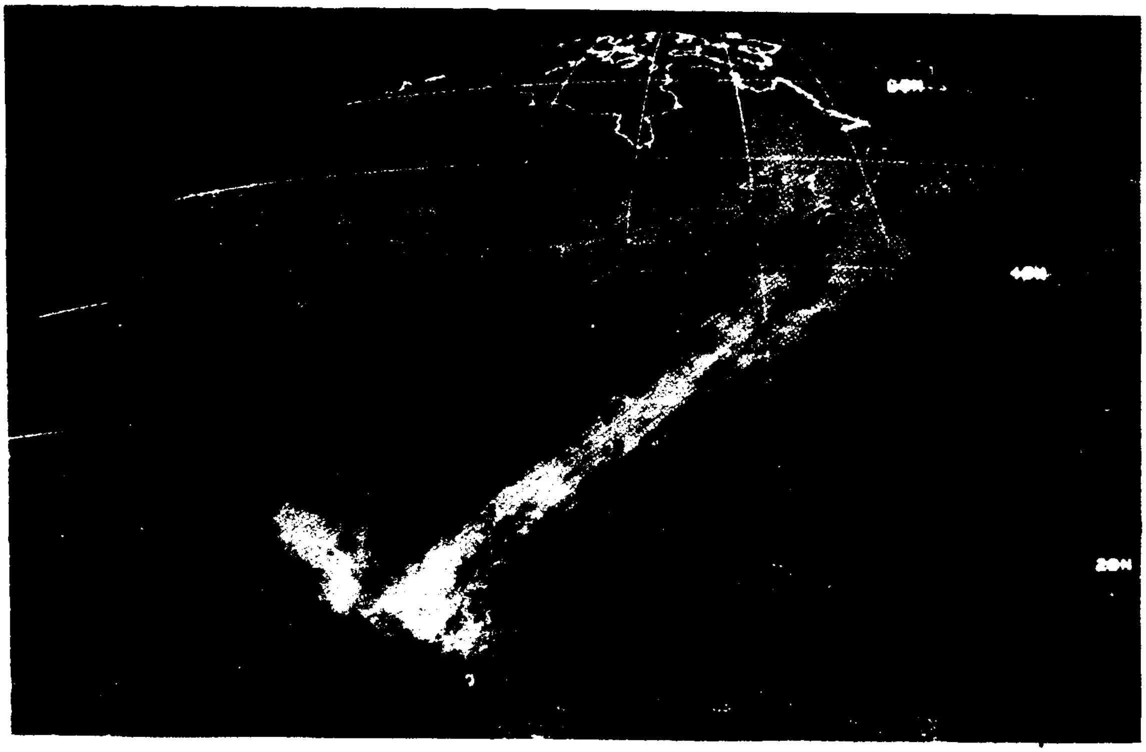


Figure 3-10. Polar Surge Reaches the Yucatan Plains. The front shears in westerly flow aloft. Moist low-level easterlies over the Bay of Campeche converge with colder air behind the front.

SKY COVER. Clear skies dominate as the trade wind inversion intensifies. The most significant improvements are along the Bay of Campeche where upper-level westerly flow is strongest. Low-lying stratus with bases from 1,000 to 1,500 feet (330-460 meters) forms over the coast during the night, while thicker stratiform clouds occur with an intense frontal passage. Because of drier air, cumuliform cloud bases average 3,000-4,000 feet (915-1,220 meters) as opposed to the 2,000-3,000-foot (610-915-meter) bases during the summer.

WINDS. Along and behind the passage of modified cold fronts, strong pressure gradients may increase wind speed and shift the direction to northwest or north. Winds greater than 20 knots are common along gust fronts. These conditions are evident along the Mexican coast, but more intense outbreaks can affect inland regions as far south as Belize City.

THUNDERSTORMS. Thunderstorm incidence during December, January, and February is generally less than

once a month. But by April, an increase in insolation improves chances of seeing a thunderstorm to 20-35 percent. As surface heating stimulates convective activity, cloud tops reach beyond the inversion to 9,000 feet (2,745 meters). Orographic lifting can send them higher.

PRECIPITATION. During the dry season, mid-latitude cold fronts regularly affect the region's weather for 12-48 hours at a time. These fronts are the primary producers of dry season rainfall, which is mainly showery and accounts for only 10-20 percent of annual precipitation totals. Occasionally, there is enough instability to produce a thundershower, rarely severe. Isolated areas of the north coast are relatively moist, but this is caused by moist, low-level northeasterly convergence into approaching polar fronts. For example, Coatzacoalcos, on the western edge of the Bay of Campeche, gets more than 20 inches (508 mm) of rain during the dry season, 9.8 inches (249 mm) of which falls in December. Merida, however, on the eastern edge of Campeche Bay 500 miles northeast of Coatzacoalcos, gets only 5 inches (127 mm) of rain during the dry season (1.2 inches/30 mm of it in December). Merida is on the leeward side of low-level northeasterlies, while Coatzacoalcos is favorably positioned to receive unobstructed northeasterly flow. The low-lying southern coast of Belize and neighboring Guatemala are flanked by mountainous terrain and therefore have wet winters. Average dry season precipitation amounts here range from 17 to 22 inches (431-550 mm) with only March and April receiving less than 2.5 inches (64 mm) a month.

TEMPERATURE. The dry season inversion suppresses cloudiness; humidities are lowest of the year. These conditions allow for classic latitudinal temperature distributions. Daily lows average 71°F/21°C in December, 74°F/23°C in April. December Highs range from 84°F/29°C to 93°F/34°C in the southern sections. Puerto Barrios has reached 109°F/43°C in March and 110°F/43°C in April. Farther north, Belize City sees lows of 68-74°F (20-23°C) and highs of 82-88°F (28-31°C). Chetumal, Mexico, has lows of 66-75°F (19-24°C) and highs of 81-86°F (27-30°C).

FREEZING LEVELS. The freezing level on the Yucatan Plain is a function of latitude. Merida and Vera Cruz come under the influence of regular mid-latitude intrusions, while Belize City remains under the control of trade wind moisture throughout the dry season. Figure 3-11 shows freezing level height, month by month, over Belize City, Vera Cruz, and Merida.

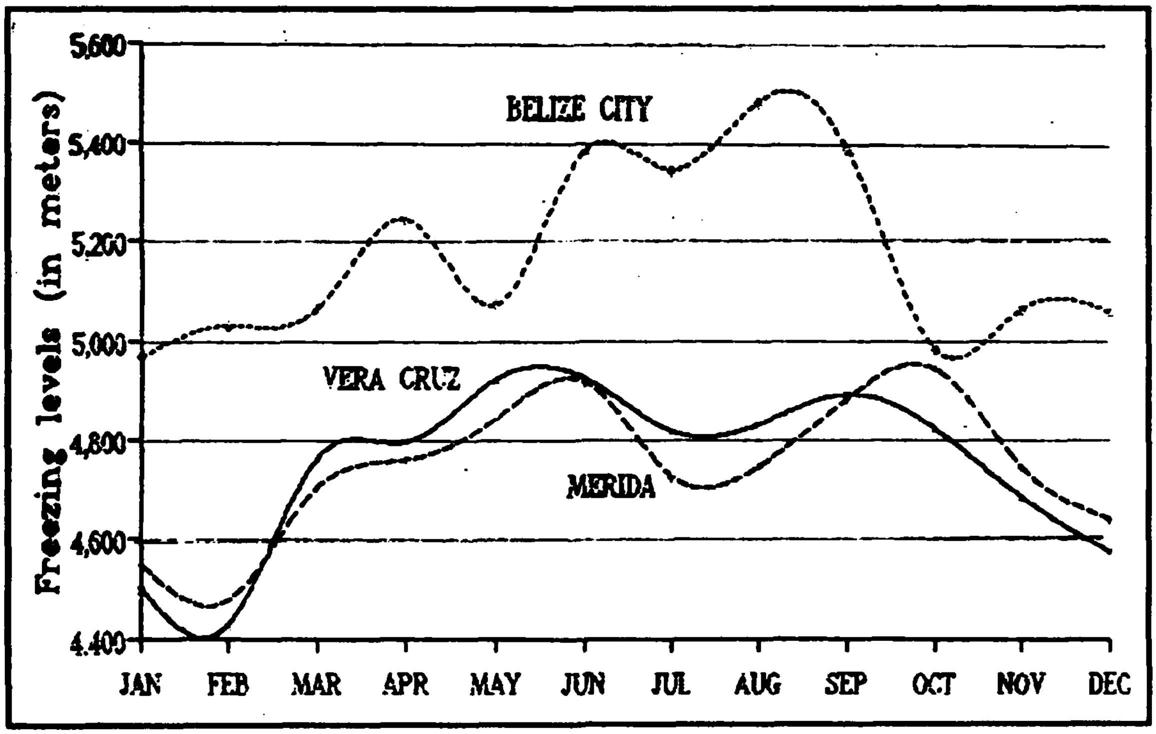


Figure 3-11. Freezing Levels for Belize City, Vera Cruz, and Merida.

GENERAL WEATHER. Intense surface heating and an upper-level wind shift are the dominant transition weather features. Clear skies promote diurnal convection while upper-level winds encourage vertical development. The moist northerlies erode subsidence aloft (at 500 millibars) and the tradewind inversion. A rare polar surge early in the transition period (shown in Figure 3-12) is the other significant weather factor.

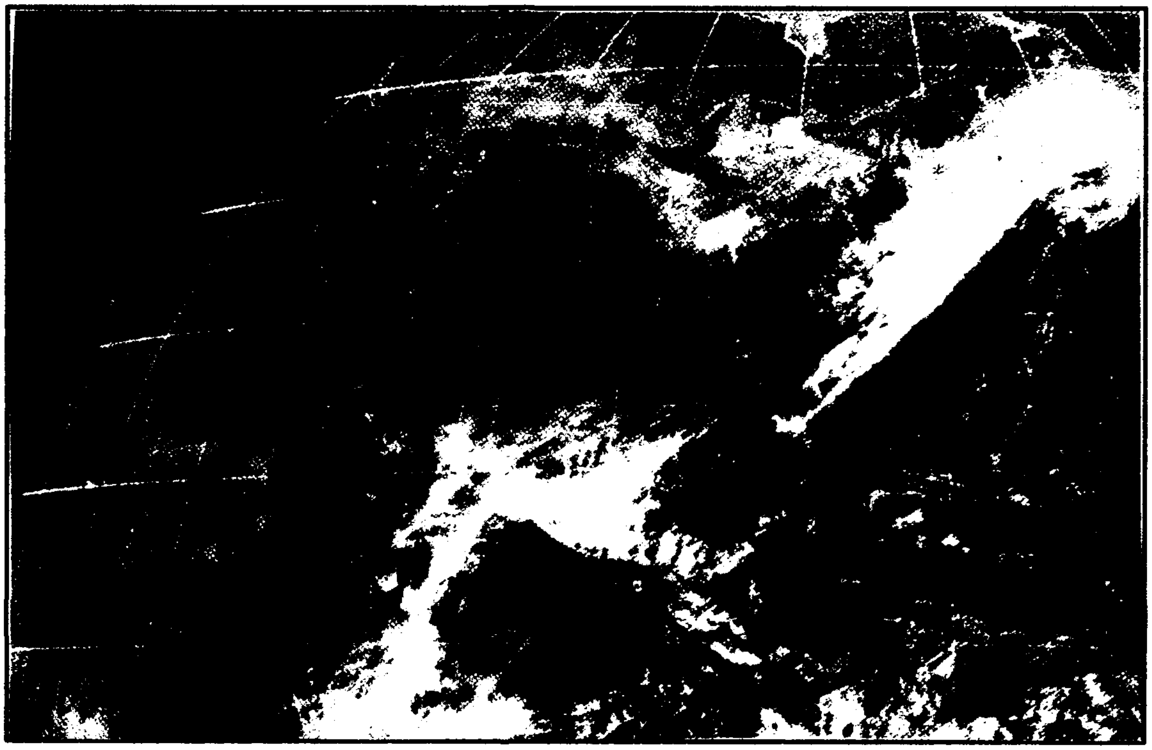


Figure 3-12. A Late Spring Polar Surge (17 March 1979 Imagery).

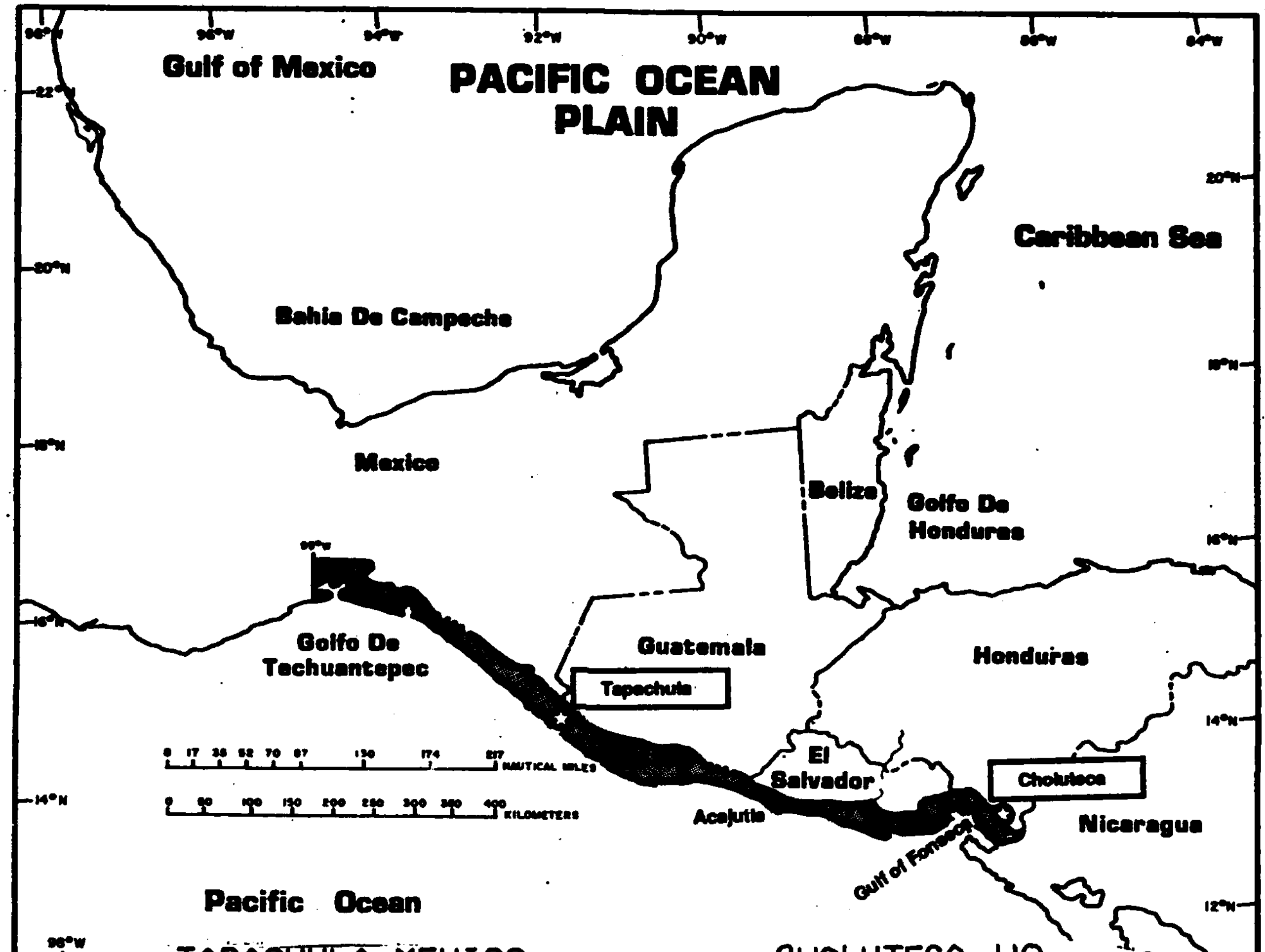
SKY COVER. There is a pronounced increase in mean sky cover during the dry-to-wet spring transition season. Mean sky cover is between 50 and 55 percent over Mexico and slightly higher in the south. Caribbean coastal locations begin to see more cumuliform cloudiness in May. Tops may reach 17,000 feet (4,870 meters) in the south, and 12,000 feet (3,620 meters) in the north. Bases are between 2,000 and 3,000 feet (610-915 meters) MSL. The north may see stratiform and cirrus cloudiness in association with frontal passages. Low ceilings may extend inland for 50 miles wherever subsidence has quickly built in during weak frontal passages. April and May have the highest frequencies of visibilities less than 3 miles.

WINDS. During frontal intrusions, winds become north or northwesterly at 10-15 knots, and may persist for up to 12 hours in strong surges. Seaside villages in Guatemala and southern Belize see higher wind speeds from channeling caused by local topography; speeds increase above the mean by 5-10 knots and direction can change by 45-90 degrees.

PRECIPITATION. With the onset of intense surface heating, precipitation doubles from April to May in the southern portions of the Yucatan. By May, all locations except those on the northwest coast of the peninsula are getting 4 inches of rain, or more, a month.

TEMPERATURES AND HUMIDITIES increase throughout the transition. April is pleasant, relatively dry, and clear. But by May, temperatures are in the mid- to upper- 80s°F (30-32°C), with humidities near 80%. Extremes can reach 100°F (38°C); all locations see highs over 90°F (32°C) on at least 10 days in May. Lows are mainly in the upper 70s°F (25-26°C). Nighttime lows rarely dip into the upper 60s°F, or about 21°C.

3.2 THE PACIFIC OCEAN PLAIN



TAPACHULA MEXICO

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	95	84	67	.3	89	74	0	1.3
FEB	95	85	68	.2	90	75	0	.5
MAR	97	86	65	1.3	92	77	0	2.2
APR	99	87	72	4	91	79	2	3.3
MAY	98	86	72	10.2	91	79	8	3.2
JUN	99	84	70	17.4	89	77	8	8.4
JUL	99	85	72	14.6	90	77	10	4.8
AUG	99	86	72	13.9	89	77	10	5.3
SEP	97	84	72	18.8	88	77	9	7.8
OCT	95	84	70	16.5	89	77	6	5.3
NOV	95	85	70	2	89	77	2	6.8
DEC	95	84	68	.8	89	76	1	4.1

CHOLUTECA HO

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	101	84	59	.T	92	76	1	0
FEB	104	86	61	.2	94	77	0	.5
MAR	106	87	66	.4	96	79	1	.2
APR	105	88	68	1.9	95	81	4	2.3
MAY	106	85	70	11	92	79	15	5.1
JUN	102	83	68	13.9	89	77	21	4.1
JUL	100	84	64	7.5	91	77	16	2.7
AUG	102	84	65	9.2	92	77	16	3.2
SEP	100	82	66	16.6	89	75	24	3.8
OCT	97	82	64	13.9	88	76	17	3.6
NOV	97	83	63	1.3	90	76	6	1.3
DEC	99	84	63	.2	91	76	2	.5

Figure 3-13. The Pacific Ocean Plain. This is a narrow strip of coastal plain that runs along the Pacific Coast from the Gulf of Tehuantepec in Mexico, through El Salvador, and to the Gulf of Fonseca in southern Honduras. Steep mountains, rising to 10,000 feet (3,050 meters) in Guatemala, clearly mark the inland Pacific Plain boundary, which is officially designated as the 500-foot (150-meter) contour through Mexico, southern Guatemala, and El Salvador. Summaries for Tapachula, Mexico, and Choluteca, Honduras, are inset.

PACIFIC PLAIN GEOGRAPHY

The Pacific Plain stretches inland from the Pacific for 20 to 30 miles (32 to 48 km). Elevations then rise rapidly. Inactive volcanic peaks reach to well over 10,000 feet (3,050 meters) in southern Guatemala and northern El Salvador, some within 50 miles (80 km) of the ocean. The plain is interrupted only briefly in western El Salvador near San Salvador where the mountains spill all the way down to the Pacific.

Scattered areas of marshland and mangrove swamps, well supplied by streams and lagoons, lie along the northern and eastern coasts of the Gulf of Tehuantepec. This kind of flat terrain reappears in El Salvador and continues to the Gulf of Fonseca. The entire plain is mostly grassland with isolated patches of scrub trees. It is surprisingly free of inlets and bays and is therefore not heavily populated, especially in the northwestern portion.

The close proximity of high mountains to the coastal plain has a significant effect on regional weather patterns. Small changes in windflow direction result in dramatic changes in weather. These effects are most noticeable with the low-level southeasterly flow of summer. During this period, the mountains may be shrouded in low clouds and frequent rainshowers, but the plain is kept dry by the stability of sinking air from the mountains.

GENERAL WEATHER. The Monsoon Trough and land/sea breeze convergence are the primary low-level weather controls during the summer. Aloft, weak anticyclonic outflow and TUTT cells sustain large-scale convection. Figure 3-14 illustrates the extensive large-scale convection and the apparent source: a mid-latitude cold front.

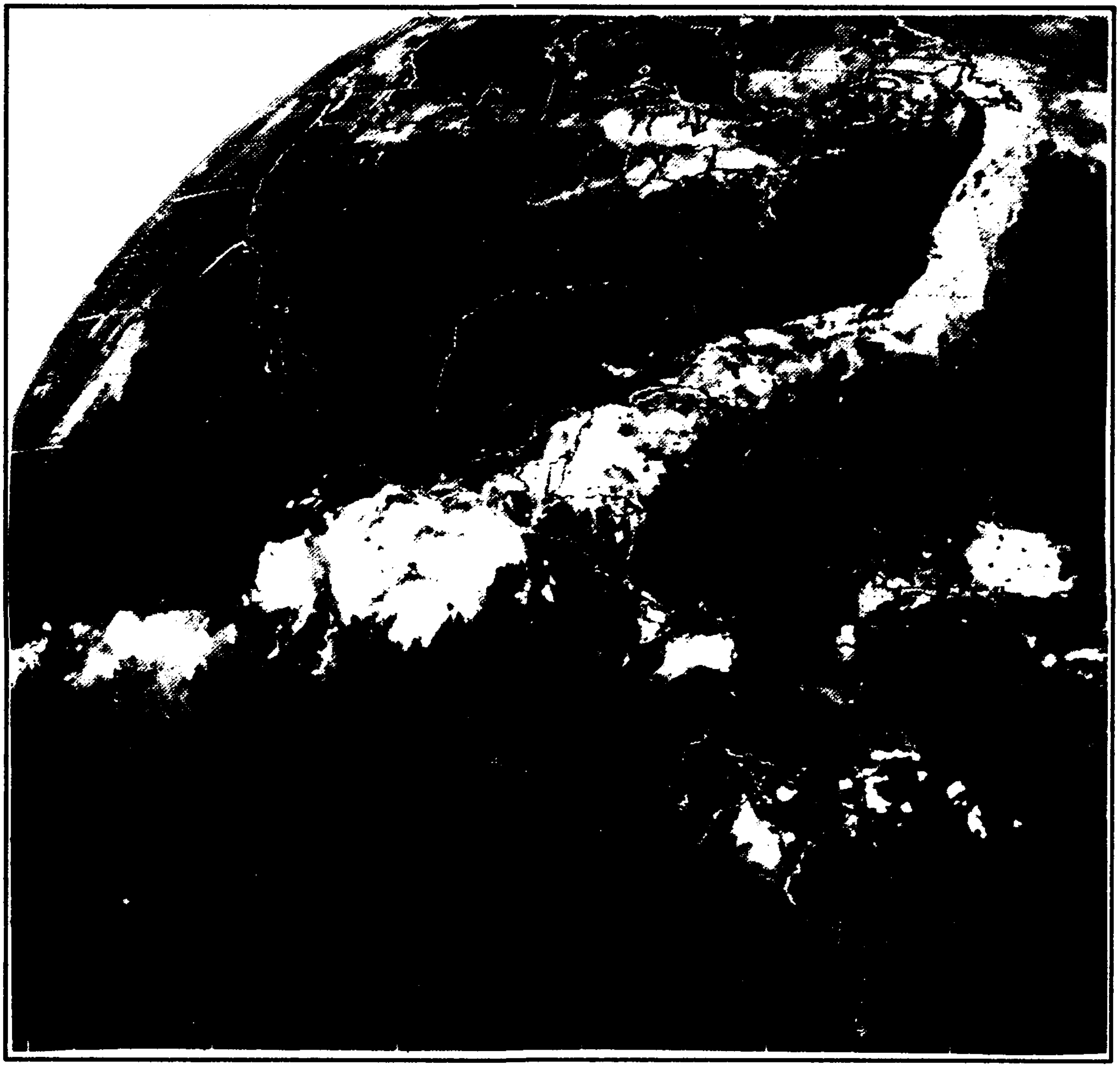


Figure 3-14. Low-Level Flow Organizes into a Tropical Depression. This 15 June 1980 satellite imagery shows tropical Pacific moisture converging with an early summer upper-level trough along the Pacific Plain.

A weak low anchored off the northern coast in the Gulf of Tehuantepec, along with sea breeze moisture, combine to produce frequent wet season thunderstorm activity. Figure 3-15 shows thick cloud cover along the windward mountain ridges of the region; orographic uplift is the trigger for this extensive cloud line. Mesoscale convergence (nocturnal squall lines) complete the diurnal wet season rainfall cycle; however, this offshore activity is the result of interaction between the Monsoon Trough and the land breeze.

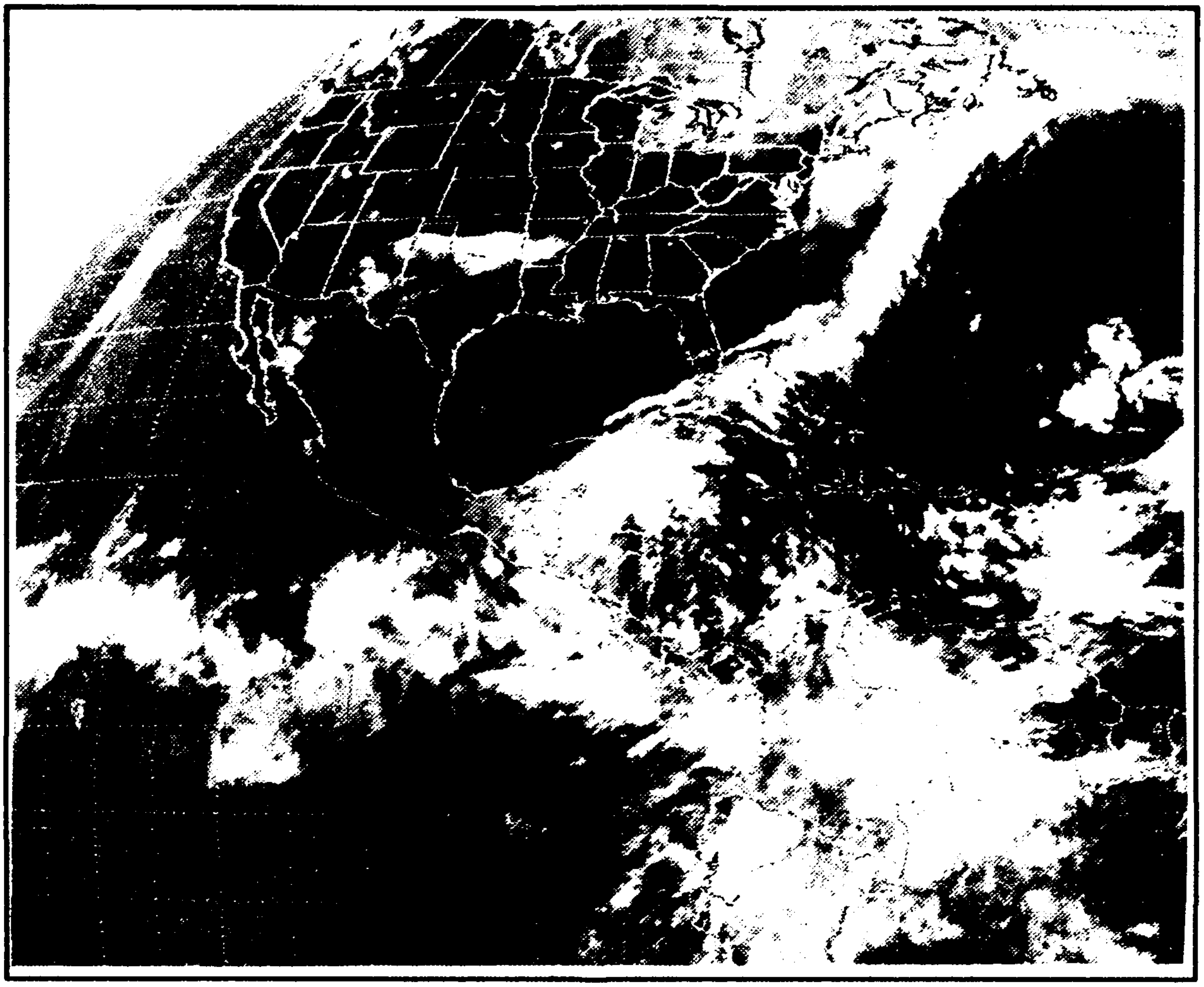


Figure 3-15. Squall Line Development over Southern Portion of Pacific Plain. In this 6 October 1980 satellite imagery, sea breezes push cloud clusters onshore. Note how the mountain ranges to the east block Caribbean moisture from penetrating the northern half of the region.

SKY COVER. Diurnal cloud cover varies widely over short distances, but daily afternoon convection produces coverage of 5/8ths or more along windward slopes. Bases average 3,000 feet (915 meters). Tops average 10,000 feet (3,050 meters), but may exceed 20,000 feet (6,100 meters) during heavy convective episodes. Mountain slopes are generally clear from 0700 to 1000 LST, the time of the land-to-sea breeze transition. Ceiling frequencies for Acajutla, El Salvador (shown in Figure 3-16), are similar to those for Choluteca, (Figure 3-17) but lower ceiling frequencies overall represent Acajutla's higher latitude and flatter terrain. The percent frequency of ceilings for Acajutla also illustrate just how significant land breezes are in producing nocturnal convection throughout the region. The availability of Pacific moisture creates sufficient humidity to form haze and smoke during calm periods in the early morning. Radiative cooling under calm conditions in the Gulf of Fonseca may result in patchy morning fog, especially after a night of heavy rain when humidities are still around 90 percent. The double peaks in ceiling frequencies from May to June and from September to October represent the departure of the tradewind inversion and maximum southwesterly flow, respectively.

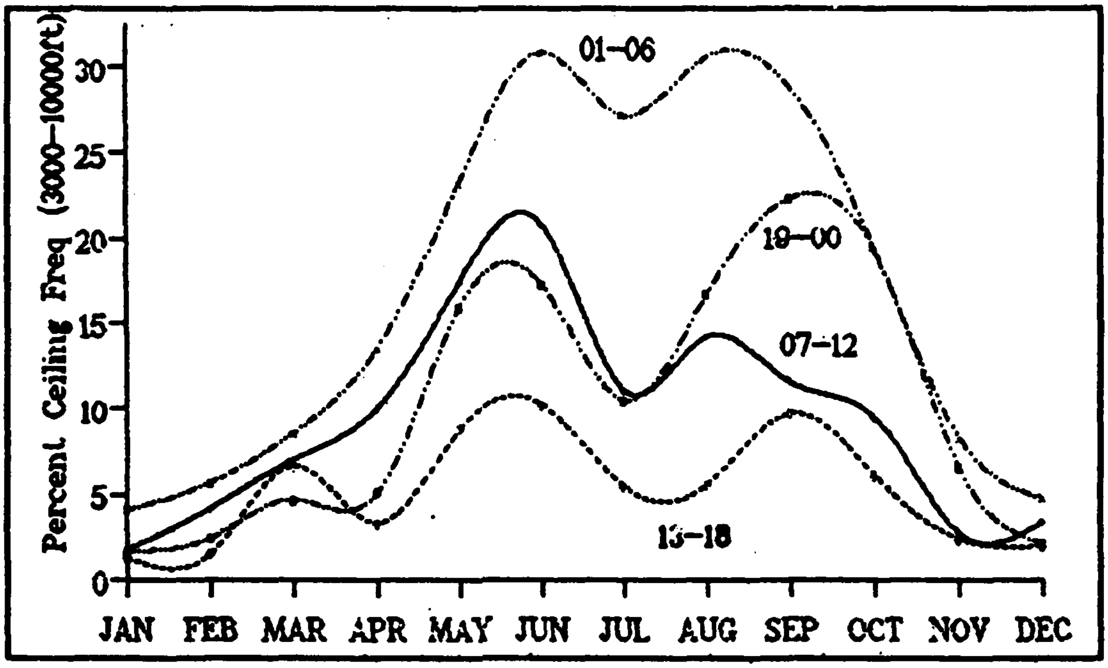


Figure 3-16. Annual Ceiling Frequencies for Acajutla, El Salvador. All times are LST.

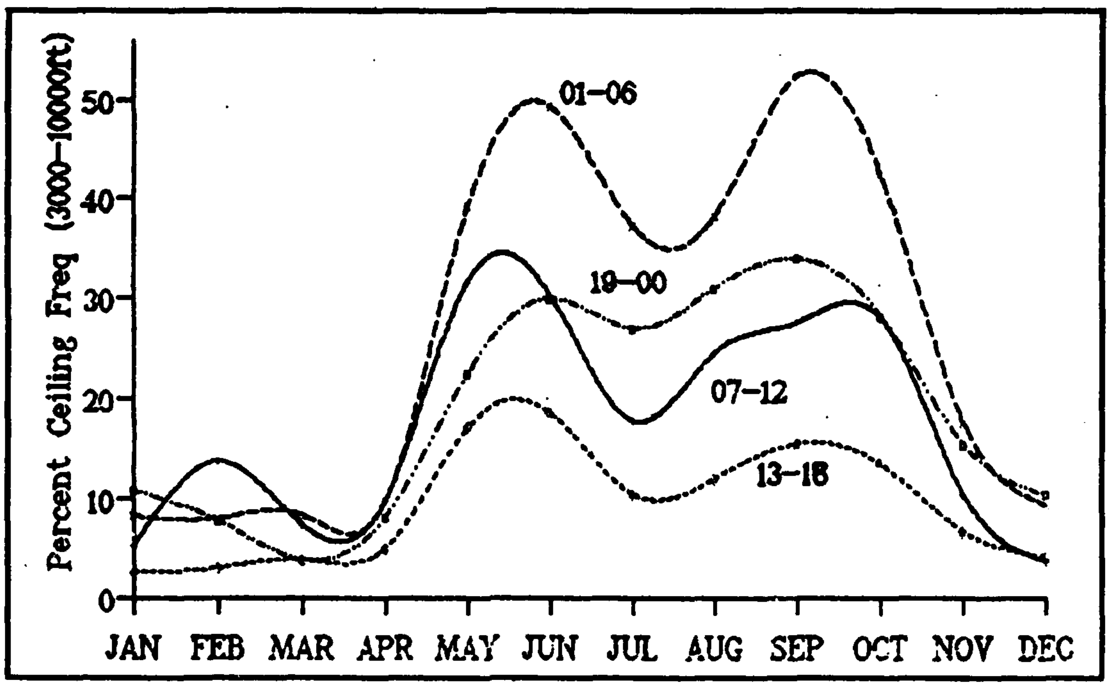


Figure 3-17. Annual Ceiling Frequencies for Choluteca, Honduras. Six-hour (LST) time blocks illustrate the relative importance of nocturnal cloud development over the Gulf of Fonseca. Complex topography contributes to the magnitude of the frequencies shown.

WINDS. On an average wet season day, sea breeze winds are less than 10 knots; nights are frequently calm. Thunderstorms may produce gusts to 20 knots. Storm-associated winds on the Pacific Plain rarely exceed 50 knots. Nocturnal mountain winds average 10-13 knots inland.

THUNDERSTORMS. The greatest occurrence of afternoon thundershowers is in August and September. August storms are related to the increasing persistence of diurnal controls, while those in September result from tropical depressions or southwesterly surges. Tops may exceed 37,000 feet (11.3 km), and bases are near 3,000 feet (915 meters). Most thunderstorms occur in the evening. The land breeze forms convection cells offshore after 2000 LST and again before 0500 LST. The reinforcing northeasterlies increase offshore flow into the Monsoon Trough.

HURRICANES have been known to affect the Pacific Plain. Some, after originating in the Atlantic and making landfall on the Caribbean coast of Central America, are carried by their momentum all the way to the Pacific side. Although friction weakens these storms as they cross from east to west, they tend to reorganize on the Pacific side. A recent example is Hurricane "Joan" which, after making landfall at Bluefields, Nicaragua, in late October 1988, continued on through the mountains all the way to the Pacific side. Joan weakened only slightly during her crossing. She reformed in the Pacific (just south of the Pacific Plain region) as Tropical Storm "Miriam." When such a storm stalls in the mountains, it can produce rains of 20 inches or more in 48 hours. For a more detailed description of the Joan/Miriam crossing, see "Caribbean Plain Wet Season."

PRECIPITATION. The Pacific Plain gets more than 50 inches (1,266 mm) of rain annually, 90% of which falls in the wet season. Most falls near the Gulf of Fonseca, where May sea breezes produce squall line thundershowers with heavy downpours. Steep mountain slopes get heavy precipitation through the combination of Monsoon Trough surges and sea breeze. Wettest months here are June, with 10-14 inches (254-353 mm), and September, with 9-14 inches (229-353 mm).

TEMPERATURE. Mean daily maximum temperatures vary slightly from north to south along the coast; the range is 89-93°F (32-34°C). Lows run from 72 to 78°F (22-26°C). Maximum temperatures are in May, when stations around the Gulf of Fonseca see highs of 100-105°F (38-41°C).

GENERAL WEATHER. Early November surface conditions are favorable for transient synoptic disturbances (polar and tradewind surges) to intensify into large-scale convective activity. These surface conditions include the warm waters of the Pacific, the position of the Monsoon Trough, and land/sea breeze convergence. By transition's end, surface conditions stabilize; the tradewind inversion strengthens with leeside adiabatic northeasterlies drying out the region.

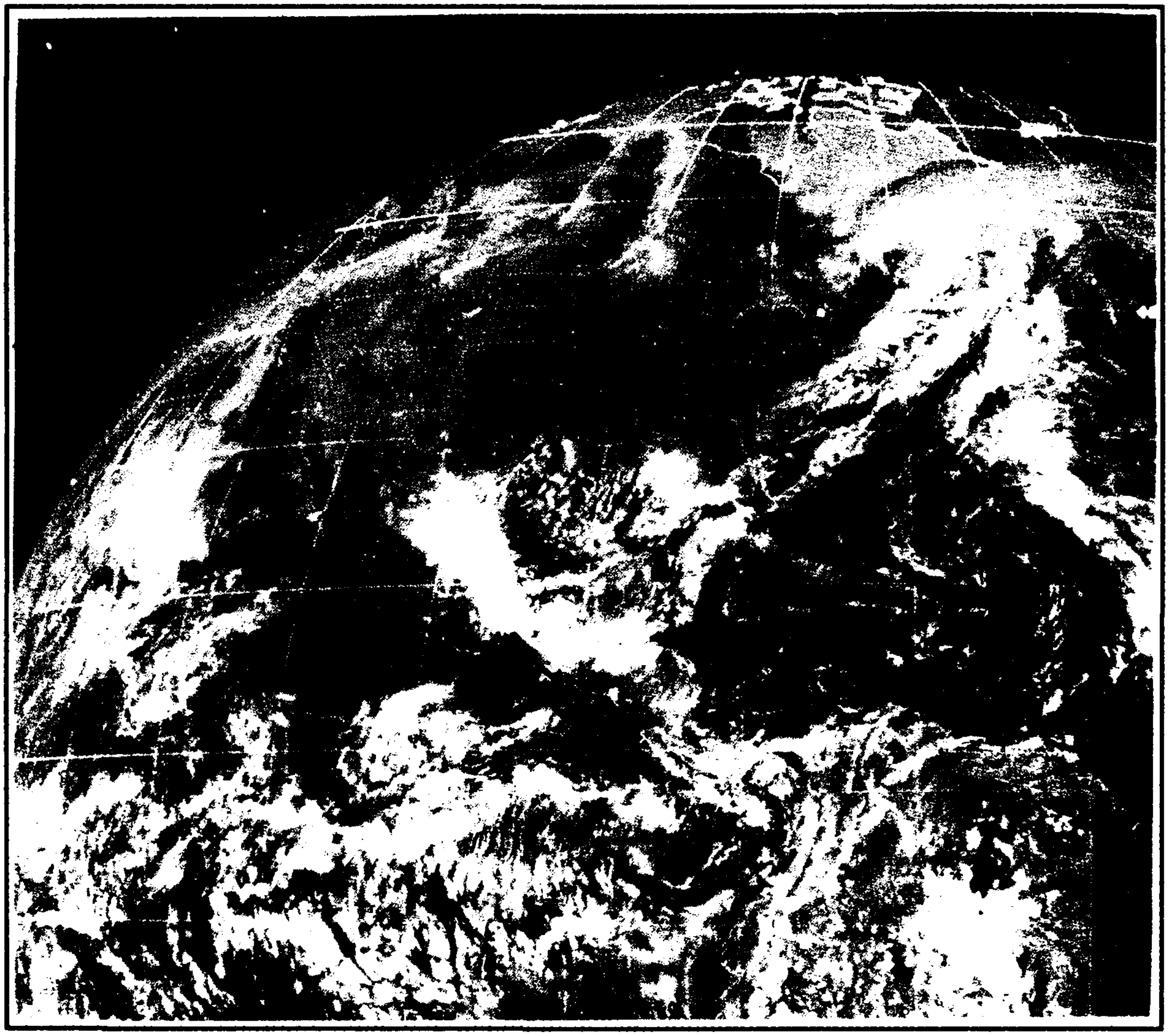


Figure 3-18a. An Equatorial Westerly Surge as seen in 1 November 1976 Satellite Imagery. Convective clusters move northward in the eastern Pacific. Southwesterly flow surges moisture into the Monsoon Trough, creating heavy (but temporary) convection that lasts for 24-48 hours before the Trough recedes to the south.

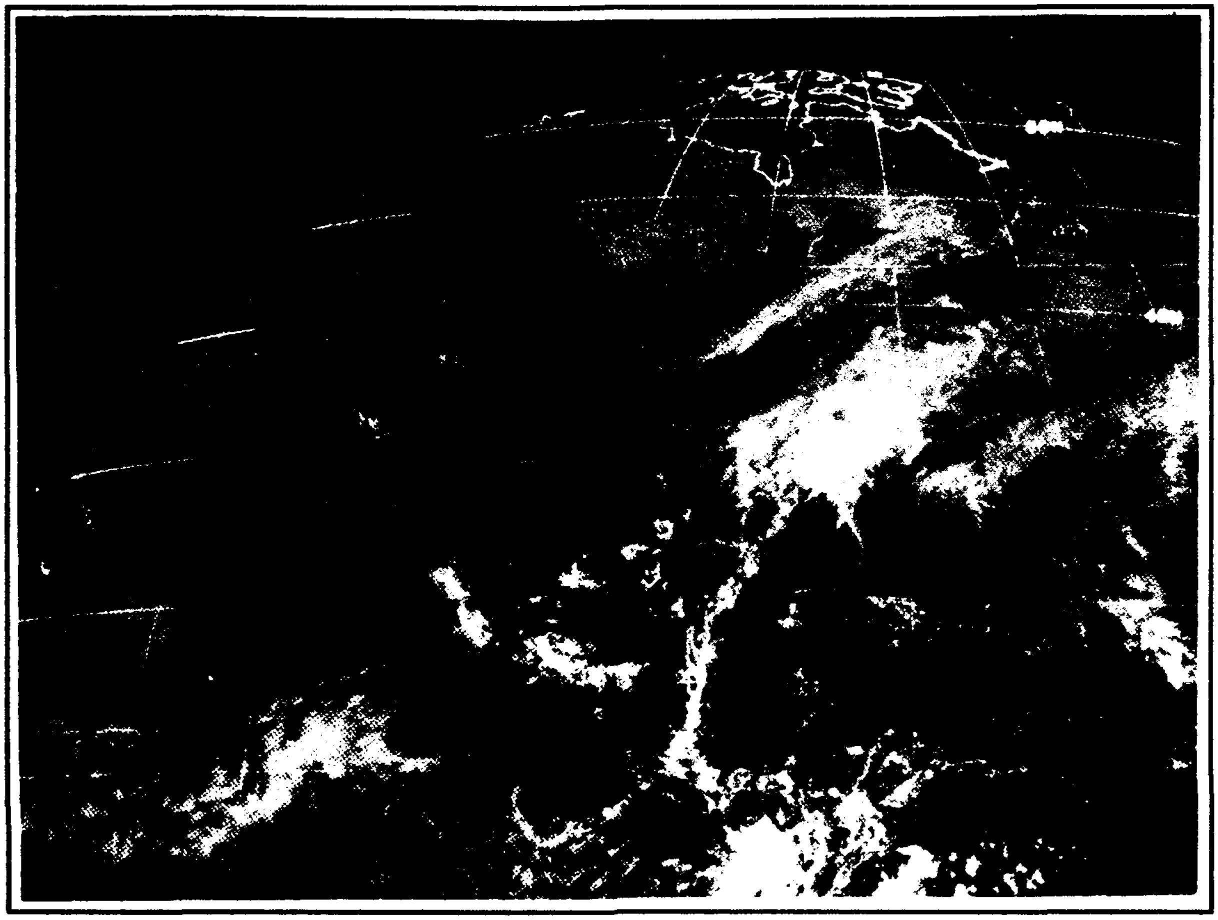


Figure 3-18b. 3 November 1976 (1200 LST) Imagery Showing the Receding Southwesterly Surge. This photo was taken 48 hours after the one in Figure 3-17a. The massive cloud cluster has moved 5 degrees to 100-105 degrees west. The well-defined east-to-west cloudline shown in Figure 3-18a at 8-9 degrees north is now disjointed at about 5 degrees north.

SKY COVER. Most cloud cover is shallow trade wind cumulus with tops from 6,000 to 8,000 feet (1,830-2,440 meters) around the Gulf of Fonseca. Bases average 2,000-3,000 feet (610-915 meters). Cirrus accompanies most frontal intrusions, but some cumulus may be mixed with stratus in stronger systems. By the end of November, skies are virtually cloudless as the northeasterly flow descends adiabatically.

WINDS. Daytime winds along the coast are 5-10 knots from the northeast. The descending mountain airflow in the interior is stronger at 10 to 17 knots, and can gust to 30 knots on clear days. The passage of a "Norte" brings north and northwesterly breezes ranging from 2 to 5 knots to brief gusts of 30 knots in more intense intrusions. Winds are calm at night.

THUNDERSTORMS. By the middle of November, the chance of a thunderstorm or shower is extremely rare; the subsidence inversion effectively suppresses convection.

HURRICANES. Although an occasional tropical storm develops over the Pacific, there are no recorded instances of a storm making landfall this late in the season. Maximum rainfall amounts in November, however, suggest that the outer canopies of these storms may produce enough vertical motion to create localized heavy showers.

PRECIPITATION. Rainfall amounts during the November transition drop off considerably. In some years, no rain at all fell in November; it is only in the Gulf of Fonseca that an abnormally wet November has been observed. Northern portions of the region normally get between 1 and 2 inches (25-51 mm) a month in November (in response to the increase in mid-latitude frontal passages), while the central and southern sections (except for the area in and around the Gulf of Fonseca) average only 1/2 to 1 inch (13-25 mm). Temporales are potentially destructive forces in this region, where rivers cannot hold excessive runoff. Temporales produce heavy rainfall with virtually no wind or thunder; upwards of 10 inches of rain can fall in 24 hours. In the absence of steering currents, such storms may remain stationary for hours. The vertical profile of moisture inflow shows continuity throughout the entire circulation and resembles, to some extent, a small hurricane without spiral banding. Since maintenance of such intense rainfall requires formation over water, coastal areas get the most rain. Storms weaken as they move inland and run out of moisture.

TEMPERATURE. Daily highs reach into the mid- to upper-80s °F (30-32°C), but humidities average between 50 and 65 percent. An occasional high will reach 100°F (38°C) in the Gulf of Fonseca where hot, adiabatic winds funnel into the Gulf. Elsewhere, 90°F (32°C) readings are found on 2 out of 3 days in November.

GENERAL WEATHER. The narrow coastal plain is dominated by the tradewind inversion and its leeside drying effect. Subsidence aloft at 500 millibars strengthens the inversion and forces prevailing northeasterly flow to descend adiabatically into the region. Only polar surges (occurring 2-10 times per season) produce light rainfall and disturb the inversion layer. Figure 3-19 shows one such disturbance. Frequently, these surges only provide some scattered stratocumulus, like those shown in Figures 3-20a and b. Along the mountain slopes, these synoptic disturbances converge with weak onshore flow to produce standing convection. Moderate to heavy showers are brief. Dry air quickly fills the convection, either through a land breeze reversal or renewed northeasterlies.

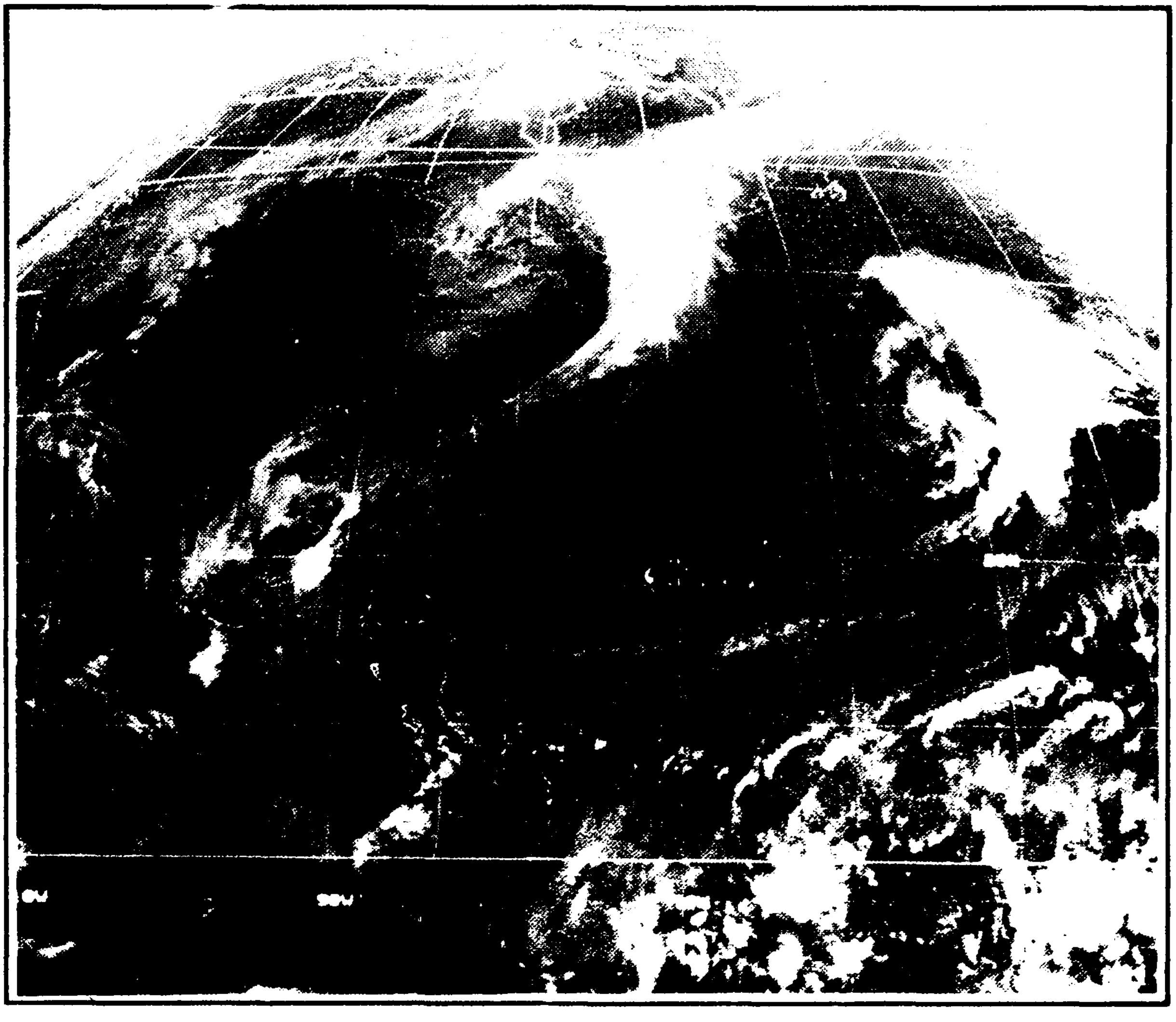


Figure 3-19. 1 April 1976 Satellite Imagery Showing Shearing of a Mid-Latitude Cold Front.

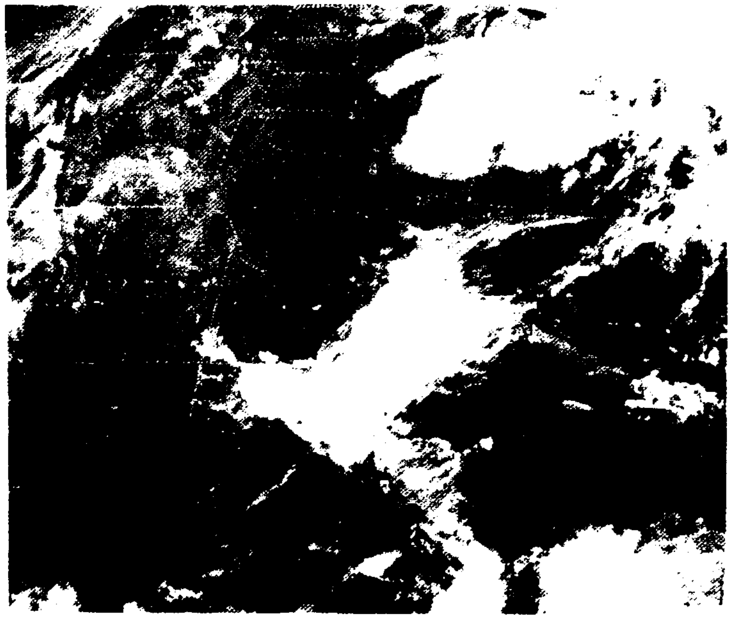


Figure 3-20a. A Mid-Latitude Disturbance (27 March 1978) Descends Over the Pacific Plain.

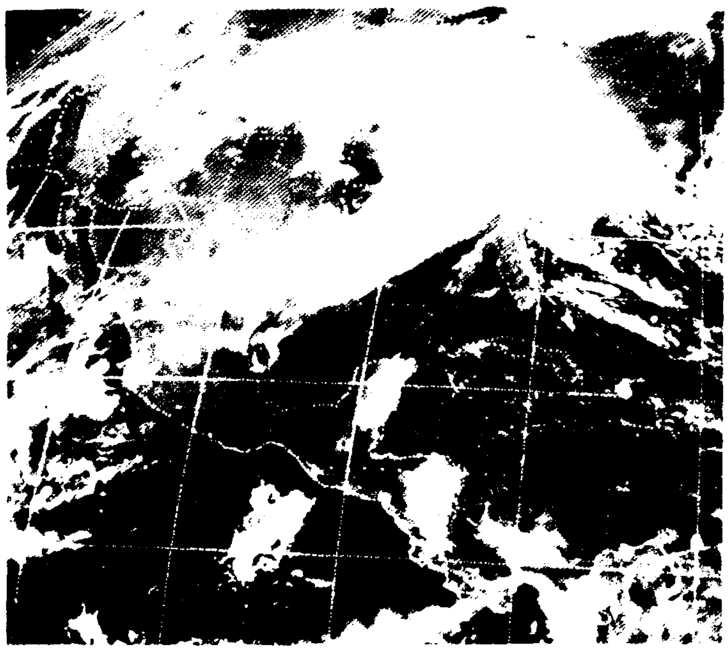


Figure 3-20b. A Sheared Polar Front (28 March 1978). Stratocumulus and dry season rainfall occur with instability from this sheared front.

SKY COVER. Skies are normally clear. Mountain slopes, however, are least cloud-free because of frontal intrusions that lift airmasses orographically. Some dry-season cloudiness occurs in the southern portions of the Plain at about 0600 LST just before the local land/sea breeze reversal; the sea breeze brings in enough moisture to create 2/8 sky cover, at most. Bases rarely form below 3,000 feet (915 meters) during the dry season; tops are 6,000-8,000 feet (1,830-2,440 meters). The daytime sea breeze is nearly cancelled by the persistent northeasterly trade wind flow, but the nocturnal land breeze in the Gulf of Fonseca is reinforced. Descending dry air occasionally acquires moisture as it sweeps through the Gulf of Fonseca to form nocturnal cumulus against terrain in western parts of the Plain.

WINDS. Throughout the dry season, northeast winds descend adiabatically down the mountain slopes, then accelerate over the lowlands of the Plains. The daily southerly sea breeze never equals the force of the dry northeasterlies, but may meet the gradient flow with enough effect to produce brief showers. Winds associated with a "Norte" can exceed 50 knots during intense polar intrusions, but gusts normally only reach 25 knots.

PRECIPITATION. Average monthly rainfall for December, January, February, and March is less than 0.6 inches (15 mm). In parts of coastal El Salvador and Guatemala, January and February rainfall averages just over a trace. In the Gulf of Fonseca area, the driest month varies from December on the coast to April inland. Low-level convergence from local effects can produce the occasional shower.

TEMPERATURES. Temperature gradients vary more during the dry season; humidities are very low. The largest gradients are in the higher elevations where peaks are snow-covered on the average of 3 days a year. The lowland slopes of the northern fringes of the region may be affected by passing cold fronts that are seldom strong enough to lower coastal temperatures significantly. San Josè, on the coast of Guatemala, has seen lows of 56°F (13°C) in December, but daytime highs are normally in the low 80s °F (27-29°C). Along the coast of the Gulf of Fonseca, cooling gulf breezes hold highs to below 85°F (29°C), while interior temperatures average well above 90°F (32°C). Locations on the coast, however, may also see 90°F temperatures if the prevailing adiabatic flow takes on a more northerly component.

GENERAL WEATHER. The gradual return of prevailing southwesterly synoptic scale flow and intensifying diurnal convection cycle are the primary weather features during the period. The "chubascos de los chiquirines," a local name for squall line development always observed in early May, are the result of the southwesterlies reinforced by a strong sea breeze. Thunderstorms, gusty winds, and heavy showers accompany these northeastward-moving disturbances.

SKY COVER. Mean sky cover increases from 45 to 57 percent through the transition. Diurnal afternoon cloudiness is reinforced by the Monsoon Trough, which strengthens the sea breeze and increases southwesterly flow. Tradewind cumulus begins to develop after 0900 LST but dissipates after 1900 as land breezes take over. Cumulus tops may exceed 20,000 feet (6.2 km), but generally remain below 12,000 feet (3.8 km). Bases average 3,000-4,000 feet AGL (915-1,220 meters).

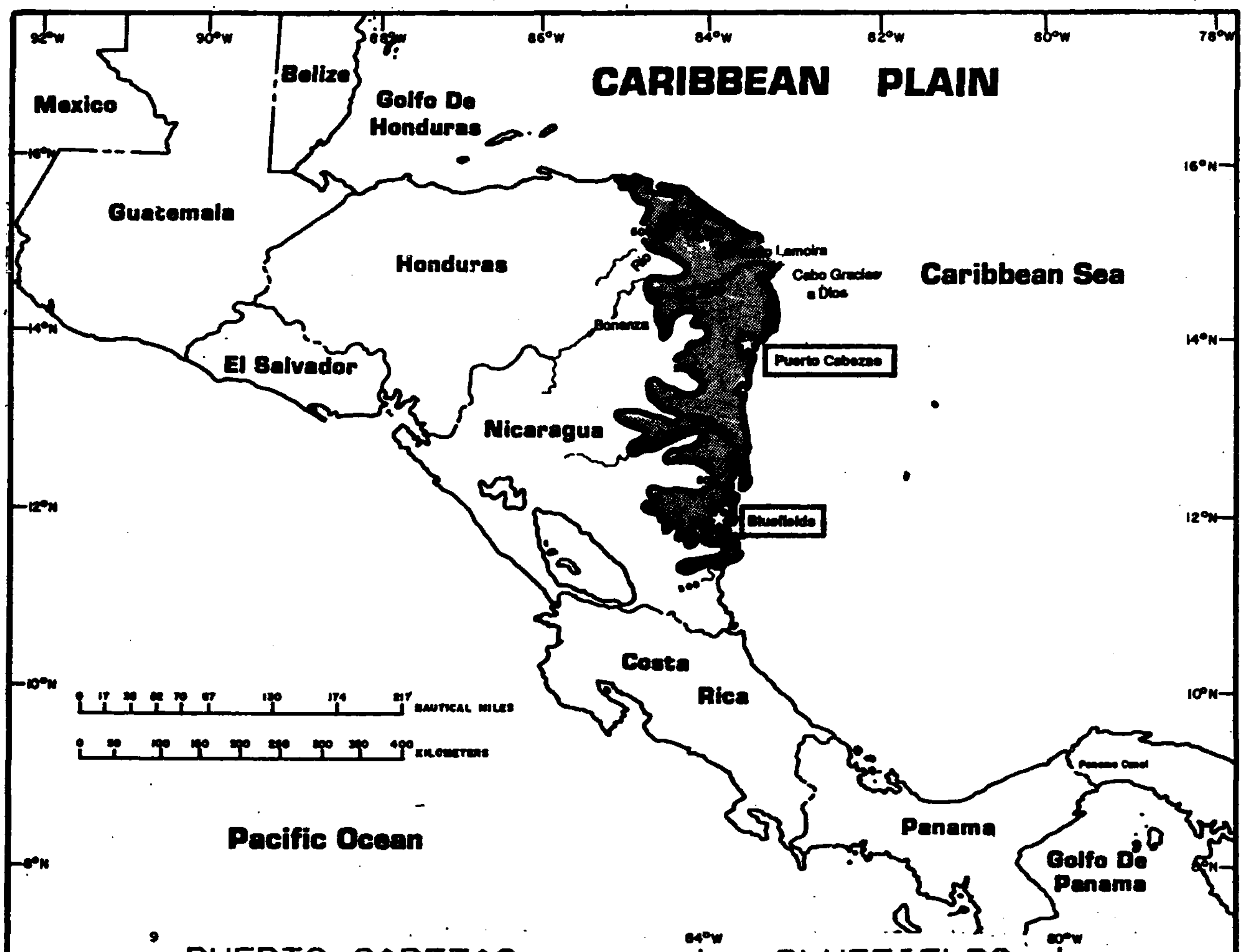
WINDS become southerly to southwesterly with the initial surges of the Monsoon Trough. Speeds average 5-8 knots, but thunderstorms or heavy convective cells may produce gusts to 20 knots. The prevailing northeasterlies average 8-11 knots and dominate inland, effectively canceling the sea breeze everywhere except along the immediate shoreline.

THUNDERSTORMS. The number of thunderstorm days increases from only 1 in April to 3-5 in May. This is because of the increase in convective cloudiness and instability introduced by the reappearance of the Monsoon Trough and the weakening of the tradewind inversion.

PRECIPITATION. By late May, heavy rainfall returns to the Pacific Plain and its inland mountain slopes. Amounts range from 11 inches (279 mm) in the Gulf of Fonseca to 4 inches (102 mm) on the northern fringes of Guatemala and Mexico. The south is wetter because of the Monsoon Trough.

TEMPERATURES. The highest transition season temperatures are in the Gulf of Fonseca; Amapala, Honduras, has recorded 105°F (41°C). Farther up the coast at San Josè, Guatemala, highs have reached 103°F (40°C). Average highs range between 88 and 93°F (31-34°C) under clear skies. Lows rarely dip below 70°F (21°C) along the water, but Choluteca, Honduras, on the interior Gulf of Fonseca plain, has seen 52°F (11°C) in May. Average lows range from 74°F (23°C) at Choluteca to 78°F (26°C) at San Jose.

3.3 THE CARIBBEAN PLAIN



PUERTO CABEZAS

	EXT MAX	AV MAX	AVG MIN	EXT MIN	PRECIP	TSTM DAYS
JAN	92	84	77	69	6.5	7
FEB	91	85	79	69	3.5	4
MAR	93	87	79	72	1.8	4
APR	94	88	82	73	2.1	4
MAY	97	89	81	74	10.5	4
JUN	93	88	82	72	16.7	12
JUL	91	86	82	72	18.9	12
AUG	95	88	81	73	13.6	13
SEP	96	89	81	73	11.8	11
OCT	97	89	79	72	12.8	12
NOV	93	86	78	71	13.4	9
DEC	90	85	78	70	10.8	7

BLUEFIELDS

	EXT MAX	AV MAX	AVG MIN	EXT MIN	PRECIP	TSTM DAYS
JAN	90	85	78	69	9.9	3
FEB	90	85	79	69	4.1	3
MAR	91	87	83	71	2.8	2
APR	94	88	84	72	3.9	2
MAY	94	88	80	73	13.7	4
JUN	94	87	80	73	19.9	6
JUL	93	85	77	73	31.5	7
AUG	97	87	79	73	24.4	9
SEP	99	89	79	72	12.5	9
OCT	94	88	80	71	13.2	7
NOV	93	86	78	70	14.3	5
DEC	93	85	77	69	14.1	3

Figure 3-21. The Caribbean Plain. This north-south strip of Honduras and Nicaragua lies between mountains inland to the west and the Caribbean Sea to the east. The portion south of the Rio Coco is commonly called "Costa de Mosquito," or "The Mosquito Coast." About 75 miles wide and 350 miles long (139 by 648 km), the plain stretches from Punta Patuca in the north to Punta Gorda in the south. The area is crisscrossed by numerous rivers east from the mountains to the sea. Broad river deltas along the coast have resulted in extensive marshlands. Insets provide climatic summaries for Puerto Cabezas and Bluefields, Nicaragua.

CARIBBEAN PLAIN GEOGRAPHY

This low-lying region is occasionally interrupted by groups of hills less than 2,000 feet (610 meters) in elevation. There are numerous rivers and streams; lagoons and small inlets extend over a large portion of the immediate coastal plain. Extensive marshlands and swamps cover the region. In Honduras, flat terrain stretches inland nearly to the hill regions. There is great seasonal variability in the size of these marshlands and swamps, but they are at their greatest extent during the summer rainy season.

An important climatic feature of the Caribbean Plain is the elevated underwater "Miskito Shelf" that extends some 100-150 kilometers off the Nicaraguan coast. These shallows offer an undisturbed haven for warm tropical water currents. Warm and moist air from the shallow water here is an ever-present source of high humidity, cloudiness, and extremely wet conditions, especially on the area known as the "Mosquito" Coast--see Figure 3-22.

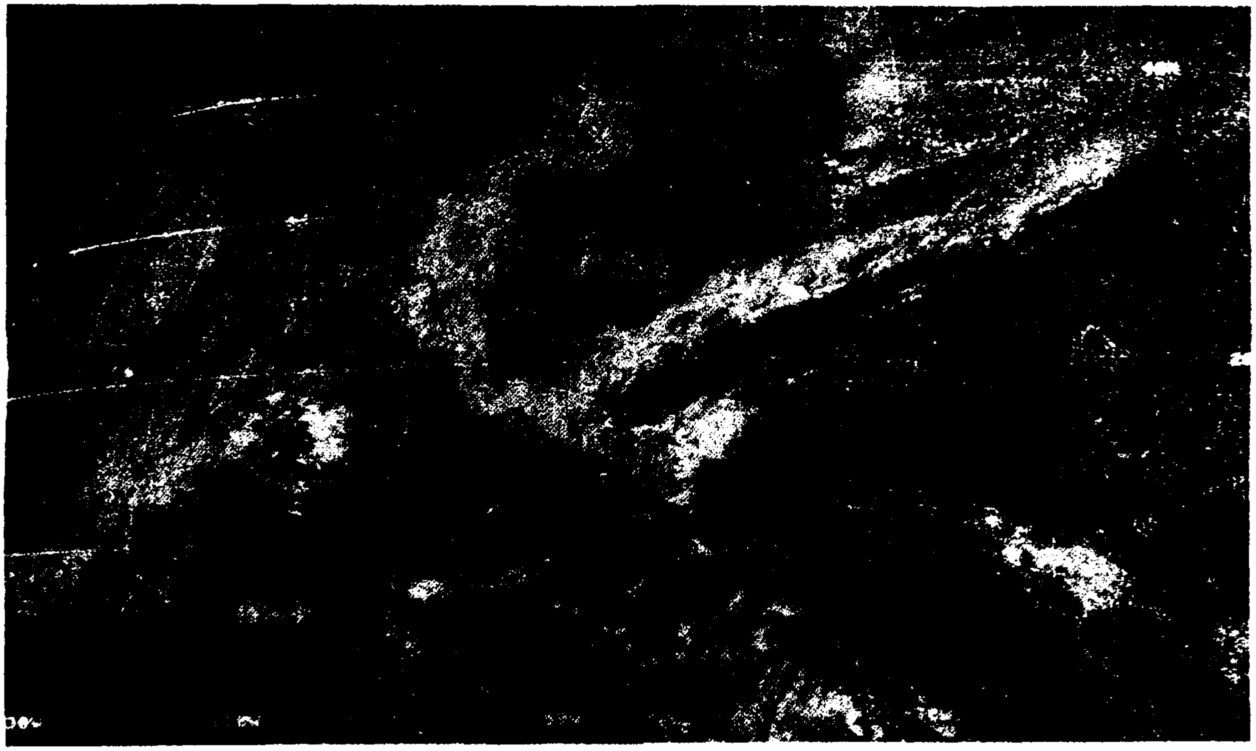


Figure 3-22. The Miskito Shelf. These shallow coastal waters off the Honduran-Nicaraguan coast are year around producers of cloud cover, as shown in this 23 November 1976 satellite photo.

Several large rivers cross the Caribbean Plain. The Patuca River (Rio Patuca) meanders through northeast Honduras enroute to the Caribbean. The Rio Coco designates the eastern quarter of the Honduras-Nicaraguan border. The Rio Grande finds its source in the mountain streams of central Nicaragua before ending in the Caribbean; most small villages in this region are found along these rivers. Tropical savanna dominates the plain, giving way to swampy grasslands nearer the coasts. Isolated areas of broadleaved deciduous forests can be found, but only in the drier soils of regions well away from the coast.

GENERAL WEATHER. Moist northeasterly tradewinds and a well-developed outflow mechanism for sustaining convection aloft at 300 millibars convert sea breeze-induced cumulus into substantial large-scale thunderstorm cells. The common weather pattern develops with the initial (0830 LST) acceleration of onshore (northeast tradewind) flow. Showers develop early in the diurnal cycle, followed by rapid vertical cumulus formation by mid-afternoon. Thunderstorm movement is westward at only 5-10 knots; their relatively slow progress across the terrain can result in 1-2 inch rainfall accumulations beneath individual cells.

SKY COVER. Mean cloudiness over the Plain is more than 75 percent in June, decreasing to about 65 percent by October. Cloud tops that form at dawn over the coast rarely exceed 6,000 feet (1,830 meters); bases are 1,500-3,000 feet (460-915 meters). As the day goes on, cumulus tops vary from 10,000 feet (3,050 meters) along the coast to 20,000 feet (6,100 meters) inland, the latter in response to orographic lift. Bases are 3,000-4,000 feet (915-1,220 meters). Figure 3-23 compares ceiling frequency below 3,000 feet at three stations. Visibilities under 3 miles are rare, but the highest frequency (23 percent) is during the day, with heavy summer rainfall.

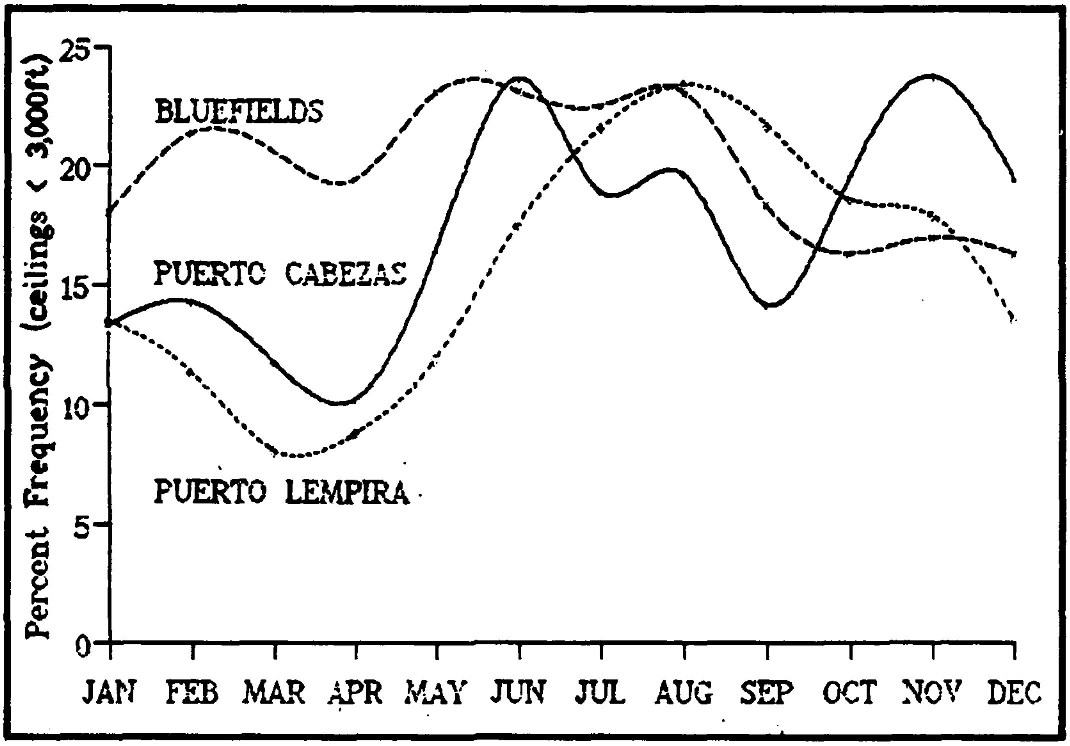


Figure 3-23. Percent Frequency of Ceilings Below 3,000 feet for Three Locations on the Caribbean Plain. The lowest ceilings occur during the wet season. Puerto Lempira shows a marked increase in low ceilings toward the latter part of the season because of mid-latitude frontal passages.

WINDS. The Caribbean Plain is dominated by the diurnal land-sea breeze phenomenon. Speeds rarely exceed 10 knots during the day, but individual microbursts and downdrafts from larger convective cells can reach 20 knots.

TROPICAL DISTURBANCES are much more likely to strike the northern part of the Plain, and with greater frequency and intensity. Damage is more likely to be caused by flooding than by high winds, even though speeds can reach 120 knots. Normally, however, winds only reach 40-50 knots along the edges of storms passing nearby. Also, easterly wave passages can create upper-level disturbances that are frequently seen in satellite imagery. These waves traverse the narrow Central American landmass as weakly developed cloud complexes of cirrus and mid-level cumulus.

The Caribbean Plain is in an area of frequent hurricane activity; a major source for hurricane development is located 300-400 miles east-northeast of Bluefields, Nicaragua. The best months for hurricanes are June through October, but they can occur in any month.

The northern half of the plain sees the most storm activity; Puerto Cabezas is near the center of Central American hurricane frequency. In 1971, Hurricane Edith hammered Gracias à Dios with 140-knot winds and a central pressure of 943 millibars.

Although the easterly wave track extends into the southeastern Caribbean by late August, hurricane centers seldom actually make landfall in southern Nicaragua south of 15° N; only three storms have done so in this century. On 18 September 1971, Hurricane Irene hit the southern Nicaraguan coast near Bluefields, the first tropical storm since 1911 to make landfall that far south. Irene recorded only 40-knot winds at Bluefields, but a reconnaissance flight reported visible damage at the actual point of landfall along the sparsely populated coastline. More recently, Hurricane Joan made landfall at Bluefields on 22 October 1988 with a central pressure of 934 millibars and 120-knot winds. After causing considerable damage, Joan moved into the interior, crossing the mountains in Southern Nicaragua. Although she weakened slightly, good outflow sustained heavy convection. Joan, like Irene, intensified and reformed as Tropical Storm "Miriam" along the Pacific coastline in the Nicaraguan Lakes region, which see. Precipitation totals for this storm were sketchy, but Bluefields got 5-10 inches and 15 inches were reported in the mountains. There was extensive flooding. An estimated 400 miles of roadway was washed away. Figure 3-24, prepared with data from the National Hurricane Center in Miami, shows Joan's track from 20 October as she approached the Nicaraguan coast to 25 October when she moved off into the Pacific as Tropical Storm Miriam.

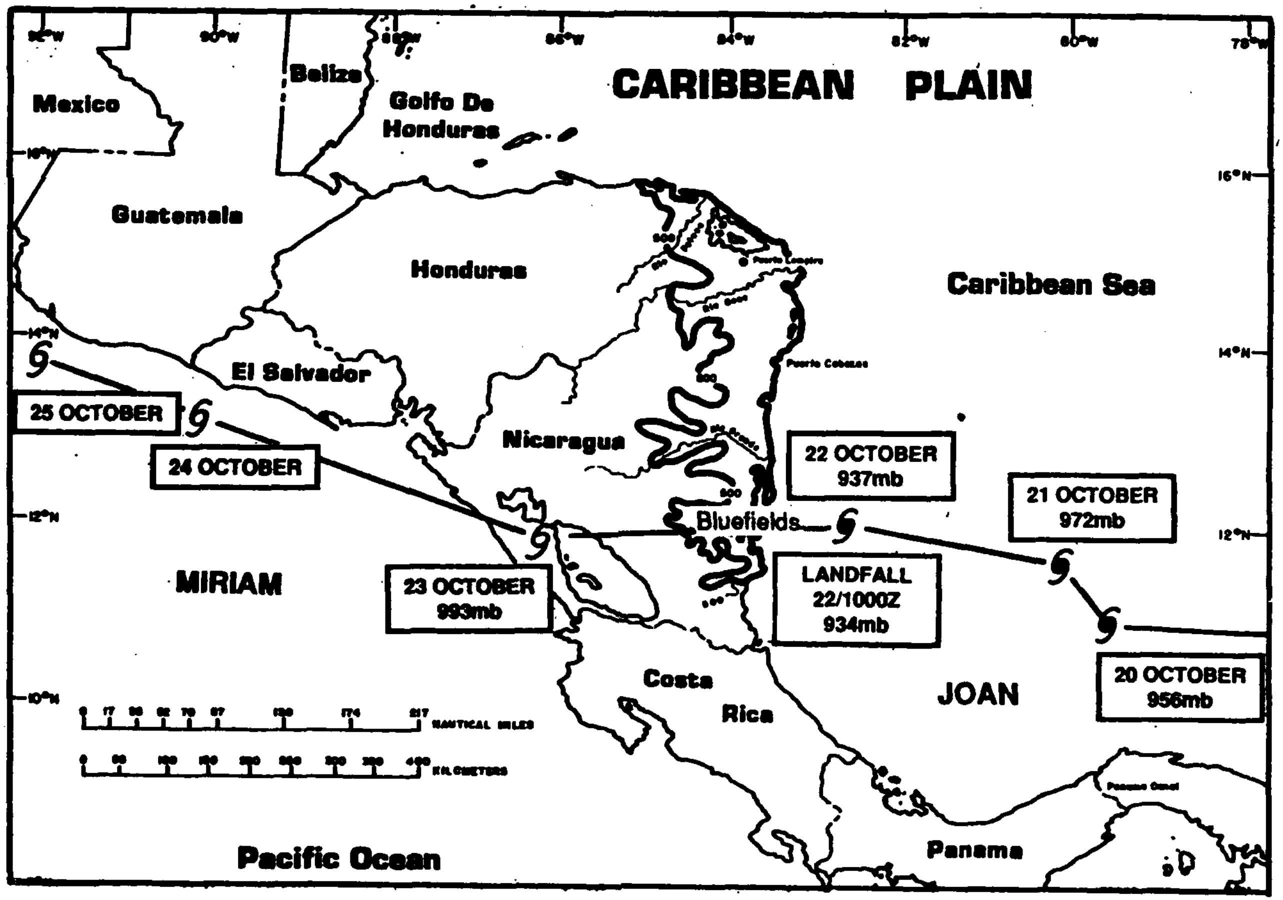


Figure 3-24 Hurricane Joan/Tropical Storm Miriam Track, 20-25 October 1988. (From an initial report provided to USAFETAC by Dr. Hal Gerrish, NHC.)

THUNDERSTORMS occur on 6-14 days a month during the wet season; one or two are severe, and associated with tropical disturbances and surges in the Monsoon Trough.

PRECIPITATION. The Caribbean Plain sees the greatest amount of wet season rainfall in all of Central America--the annual average is more than 100 inches at all locations. Three factors contribute: (1) the absence of topographic barriers to the predominantly northerly flow, (2) a persistent trade wind blowing off the Miskito Shelf, and (3) frequent hurricane activity. These three factors alone are responsible for 70 percent of the annual precipitation here. Northern sections are slightly wetter in the fall because of increased hurricane activity there. For example, Cabo Gracias a Dios, Honduras (with a 4-year period of record), receives 17 inches (432 mm) in September and 19.8 inches (503 mm) in October, while Bluefields gets only 12.3 and 13.6 inches (312 and 345 mm). But overall, the Southeastern portion of Nicaragua near Bluefields is one of the wettest locations in the Caribbean Basin; annual rainfall there averages 159 inches (4,039 mm). Cabo Gracias a Dios, at the northeastern tip of the region, averages 154 inches (3,912 mm), but Puerto Lempira, up the coast to the north and west, gets only 105 inches (2,667 mm). Bonanza, in north central Nicaragua, gets 119 inches (3,023 mm), while Puerto Cabezas, on Nicaragua's central coast, gets 123 (3,124 mm).

TEMPERATURE variations during the Caribbean Plain wet season are small, but it is warmest in early May before the daily convective cycle begins. Increases in cloudiness dampen insolation by late July, and temperatures decrease. High sea surface temperatures warm the air over the land surface at night. The average high at Cabo Gracias a Dios is 86°F (30°C); at Bluefields, it is 88°F (31°C). Lows are uniformly 73-74°F (23°C) on the coast, but slightly warmer inland.

GENERAL WEATHER. The transition weather pattern is dominated by distinct vertical moisture profiles. The tradewind inversion separates moist northeast tradewinds and sea breezes from drier, subsident westerly flow aloft. The diurnal cumuliform development cycle is not altered, but tradewind cumulus cannot penetrate the tradewind inversion; intense shower and thunderstorm activity is therefore reduced. Typically, only light to moderate showers of short duration develop within smaller convective cells.

SKY COVER. Coastal skies gradually change from cumulus with tops above 15,000 feet (4,575 meters) to clouds with tops below the inversion at 8,000 feet (2,440 meters) Stratiform decks between 2,000 and 4,000 feet (610-1,220 meters), found at dawn in calm conditions, give way to cumulus by midday. In the north, the intensity of the inversion suppresses convective development. Inland locations close to the bases of mountains see drying and only scattered cumulus by afternoon. Bases are 4,000-5,000 feet (915-1,525 meters); tops rarely exceed 8,000 feet (2,440 meters).

WINDS. Daytime winds along the Honduran coast, intensified by the sea breeze, average 8-12 knots from the north. In central and southern sections, winds are easterly with speeds of 7-10 knots. Gusts associated with disturbances and frontal passages can reach 25 knots along coasts, and up to 35 knots on mountain slopes.

PRECIPITATION. Rainfall is heavy (8-15 inches/ 203-381 mm) along the immediate coastline, but it is still less than half the average amount for October. The persistent northerly trade wind component extends its influence southward from Northern Honduras in winter and is accentuated by a sea breeze that concentrates the moisture below the inversion layer. Locations inland are drier because moisture evaporates as air ascends through the inversion layer.

TEMPERATURES. Mild days and nights dominate the early transition period. Coastal locations average 83-86°F (28-30°C) during the day and 72-75°F (22-24°C) at night. Inland villages see similar highs but slightly cooler nights (67-71°F--20-22°C) due to radiative cooling. By the end of the transition (i.e., by the start of the dry season), strong insolation raises average coastal highs into the 86-88°F (30-31°C) range, 89-93°F inland.

GENERAL WEATHER. Subsidence becomes the primary weather control. Showers are common with weak polar surges; the only synoptic disturbance capable of temporarily weakening the tradewind inversion (mean height 6,000 feet/1,830 meters--7,000 feet/2,200 meters at Bluefields) and subsident 500-millibar flow aloft. Below the inversion layer, persistent onshore flow produces instability showers.

SKY COVER. Most daytime cloudiness is stratiform mixed with trade wind cumulus. Because of subsidence aloft (above 10,000 feet--3,050 meters) cloud tops are limited to 6,000-8,000 feet (1,830-2,440 meters) near the coast and 4,000-6,000 feet (1,220-1,830 meters) inland near the mountains, provided enough moisture is transported far enough into the interior. Bases average 3,000-4,000 feet (915-1,220 meters).

WINDS. Winds in the morning are northwesterly, oriented with the land breeze. Inland winds are northerly, usually at 8-12 knots. In the south, the sea breeze results in easterly winds by 1000 LST. In the north, the normal northerly component reinforces the afternoon sea breeze. Frontal passages can produce brief gusts to near 20 knots.

PRECIPITATION. The "dry" season on the Caribbean Plain is relatively wet in comparison with other Central American locations. Rainfall along the coast averages more than 2 inches a month, but interior locations are much drier. Northern sections can expect cloudiness and rain with virtually all frontal passages; rainfall varies from moderate drizzle lasting for 3-12 hours to short periods (2-10 minutes) of moderate rain. Southern sections, on the other hand, are seldom affected by frontal passages beyond a simple wind shift. Lower sea-surface temperature, a decrease in surface heating, and increased intensity of the trade wind inversion combine to make this season "dry." In the north, most dry season precipitation is drizzle or that from stratiform cloudiness. Southern coasts receive the most dry season rainfall.

TEMPORALES tend to form in isolated areas of low-level convergence; most occur in December. These storms can create wetter than normal dry season conditions by dumping upwards of 15 inches of rain in less than 36 hours. Lowland floods and hillside slumping or mudslides may cause extensive damage. The source region for temporales is located along the coast north of Bluefields. The Miskito Shelf discussed in "Geography" is the spawning ground for intensifying weakened cold fronts pushing southward over the northern portions of the region. Stagnating shear lines are trapped within an extremely calm environment in the western Caribbean Basin. Occasionally, a succession of frontal passages renews instability through a deeper layer of the pre-existing disturbance and generates strong shearing between the trades and the new frontal intrusion at the lower layers. These regenerated circulations, using warm Caribbean moisture, create strong vertical moisture profiles and build slowly into large convective complexes.

TEMPERATURE. Winter lowering of average sea surface temperature also lowers air temperatures. Nighttime temperatures are near 70°F (21°C), reaching 85°F (30°C) during the day under partly cloudy skies.

GENERAL WEATHER. Changes in upper-air circulation patterns allow convective activity to dominate transition weather. The migration of the Azores High and westerly flow aloft away from the region weakens the tradewind inversion. As a result, diurnal trade wind cumulus grows vertically throughout daylight hours and pushes inland.

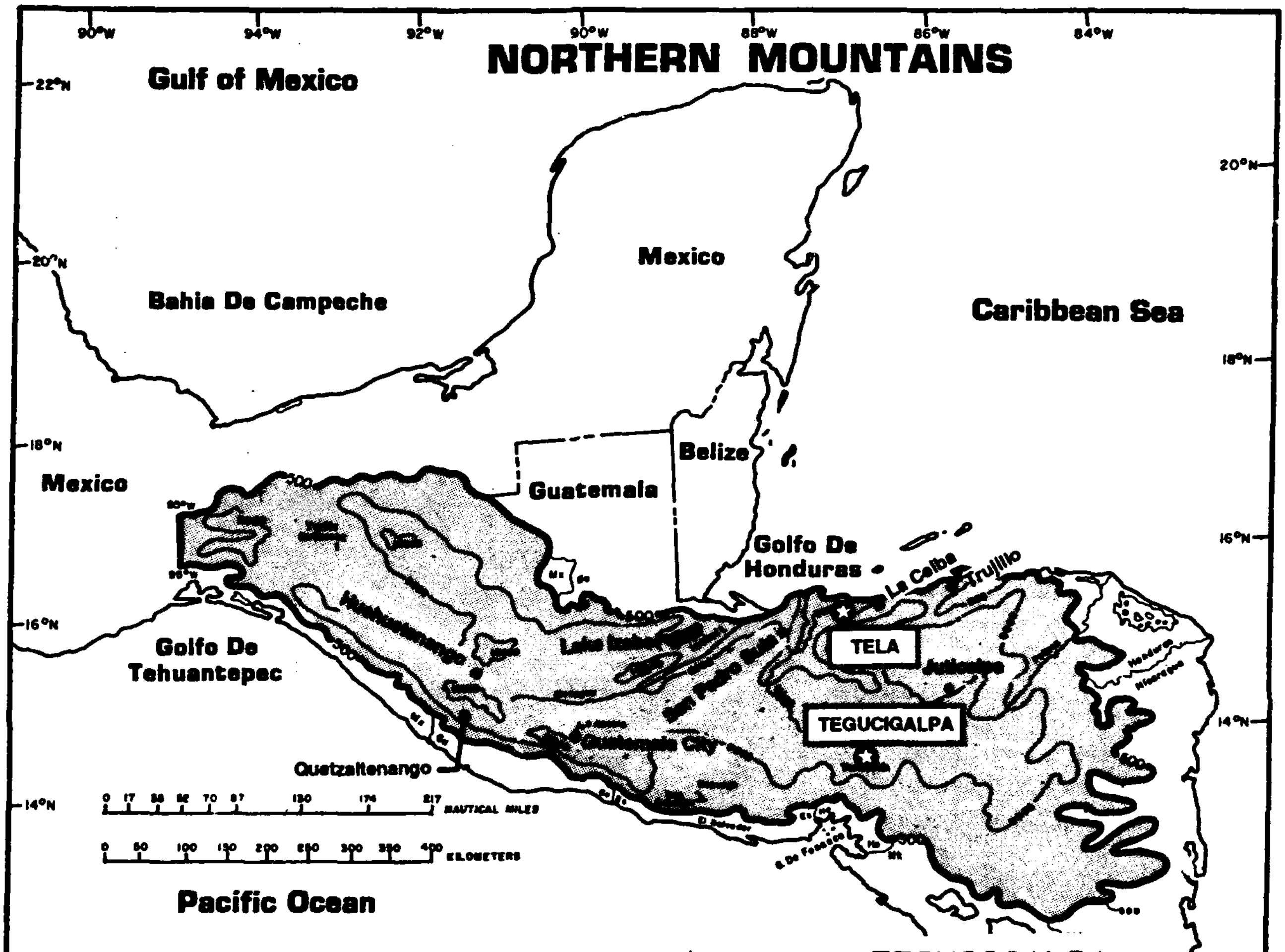
SKY COVER is predominantly trade wind cumulus. Tops reach 10,000 feet (3,050 meters) along the immediate coast, but may reach 15,000 feet (4,920 meters) inland. Bases average 2,000-3,000 feet (610-915 meters). Sky cover increases from 2/8ths in the morning to 5/8ths by mid-afternoon.

WINDS. Trade wind flow averages 5-8 knots overnight, intensifying to 6-9 knots by midday in response to the sea breeze circulation. Flow is generally east-northeasterly, but terrain in Honduras produces a more northerly component.

PRECIPITATION. Rainfall patterns become diurnal. May rainfall amounts triple (or even quadruple) April's. Most locations get at least 8 inches (203 mm) of rain in May. Cabo Gracias à Dios gets 16.2 inches (411 mm), Bluefields 13.7 (348 mm).

TEMPERATURES. Daylight hours see a substantial increase in cloud cover, particularly along the coast where average highs reach 87-89°F (31°C) before noon. Trade wind cumulus doesn't build up in the interior until about 1400 LST; the daily high there is near 90°F (32°C) in slightly drier air. Lows are in the mid-70s °F (23-25°C).

3.4 THE NORTHERN MOUNTAINS



TELA HONDURAS

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	24 HR PRECIP
JAN	89	74	59	9.8	83	67	.4	5.1
FEB	94	75	65	6.3	82	66	.4	5
MAR	96	77	58	3	87	67	1.6	3
APR	98	79	64	3.4	89	71	6.4	10
MAY	96	80	68	3.9	88	72	14.2	3.9
JUN	94	81	69	5.1	89	73	17	4
JUL	92	80	66	7	89	71	20	3.5
AUG	94	80	67	3.2	89	71	19.8	4.6
SEP	94	81	69	8.3	91	73	17.3	6
OCT	94	79	61	15	87	71	12.1	7.4
NOV	96	78	62	16.1	86	69	4	12.5
DEC	91	74	57	14.2	84	67	3.5	11

TEGUCIGALPA HONDURAS

	EXT MAX	MEAN TEMP	EXT MIN	AVG MAX	AVG MIN	TSTM DAYS
JAN	88	68	44	84	49	.1
FEB	91	70	46	87	52	.1
MAR	94	73	50	90	55	.6
APR	95	75	52	90	58	7.7
MAY	98	76	57	90	[illegible]	7.2
JUN	90	74	56	87	62	8.8
JUL	90	73	55	86	61	4.2
AUG	91	74	55	87	60	4.8
SEP	91	74	57	87	61	7.9
OCT	88	72	54	86	59	3.5
NOV	88	70	46	84	55	.5
DEC	88	69	48	84	52	.1

Figure 3-25. The Northern Mountains. The region is named for the series of mountain ranges that run from the south side of the Isthmus of Tehuantepec across central Guatemala, through most of Honduras, and into north central Nicaragua just north of the Gulf of Fonseca and the Nicaraguan Lakes. Insets provide comparative climatological summaries for Tela and Tegucigalpa.

NORTHERN MOUNTAINS GEOGRAPHY

As in most of Central America, inhabitants of the Northern Mountains classify climate according to comfort, which is largely determined by altitude. The three local "comfort zones" are:

"*Tierra caliente*" or "hot land," between sea level and 4,900 feet (1,500 meters).

"*Tierra templada*" or "temperate land," between 4,900 and 7,200 feet (1,500-2,200 meters).

"*Tierra fria*" or "cold land," above 7,200 feet (2,200 meters).

The most striking topographic features of the region are described below:

Transverse Ranges. The mountains straddling the border of Nicaragua and Honduras have an unusual orientation (northeast to southwest) in that they lie transverse to the primary ranges that lie northwest to southeast through Central America. Elevations are 3,000 to 5,000 feet (915 to 1,525 meters) MSL in northern Nicaragua, decreasing to 2,000 to 3,000 feet (610 to 915 meters) as they move southward. Smaller ranges extend eastward from the higher mountains, establishing a clear peak-valley pattern throughout Nicaragua.

Volcanos (many of which have erupted since 1800) form a line from the Volcan Tacana in southwestern Guatemala through the Volcan de San Miguel in southeastern El Salvador. These volcanic cones dominate the landscape in the southern part of this region, towering from 12,000 to nearly 14,000 feet (3,660 to 4,270 meters) in Guatemala and from 6,000 to 8,000 feet (1,830 to 2,440 meters) in El Salvador. The terrain surrounding these volcanos is much higher in southern Guatemala, averaging 6,000 to 10,000 feet (1,830 to 3,050 meters). In El Salvador, the elevation in the volcanic region is 3,000 to 5,000 feet (915 to 1,525 meters).

Extensive river valleys cut deeply into the entire region. These valleys, oriented southwest-to-northeast, are especially prevalent in northeastern Guatemala and northern Honduras. The Motagua River valley runs parallel to the northern third of the Guatemala-Honduras border. The Ulua and Aguan river valleys run 60 to 75 miles (96 to 120 km) inland from the Caribbean coast of Honduras. All three form a sharp contrast to the surrounding mountains and reach to only 200 feet (60 meters) MSL elevation in isolated areas. Other river valleys (such as the Patuca River Valley along the Honduras-Nicaraguan border and the Lempa River Valley in El Salvador) are not as extensive.

Small mountain lakes are interspersed throughout the mountains of Guatemala and Honduras and are the source of some of this area's major rivers. They also frequently create areas of marshlands in coastal regions. Two of these lakes are the Angostura Reservoir (Presa de la Angostura) and Lake Izabel (Lago de Izabel). The first is a manmade reservoir near the southern Mexico-Guatemala border. It is over 50 miles (80 km) long with an average width of 10 miles (16 km), but it expands briefly to 20 miles (32 km) at the widest point. Its elevation is 1,750 feet (534 meters) MSL. Lake Izabel, located in extreme northeastern Guatemala, is entered through the Bay of Amatique and the Gulf of Honduras. It drains into the Caribbean via the Dulce River (Rio Dulce). There are extensive marshlands on the western shore. Lake area is nearly 350 square miles (896 sq km). It is just above sea level. Mountain ridges surround Lake Izabel on three sides and are the source of the numerous streams that feed the lake.

The variability of vegetation in the Northern Mountains region is related to elevation. Grassland and isolated patches of scrub trees are predominant in mountain areas, while valleys have some broadleaved evergreen forests. Coastal plains, especially around river deltas, have extensive mangrove swamps and marshlands.

GENERAL WEATHER. An outflow mechanism aloft and large-scale convergence over significant topography are the two major weather-producing features of the Northern Mountains wet season. The Mexican 300-millibar High sustains heavy convection that is consistently fueled by orographically lifted tradewind (Pacific and Atlantic) airflow. Over the lower terrain (below 1,500 meters) in the south, moisture convergence is along the Monsoon Trough near the 850-millibar level. In either case, thunderstorms are frequent and occasionally severe.

SKY COVER. The wet season is extremely cloudy, with most days averaging 6/8 to 7/8 coverage after 1400 LST. Cumulus dominates, with bases around 3,000 feet (960 meters) AGL. Deep upper-level moisture produces prolonged periods of low ceilings and valley fog. Extensive cloudiness overrides the natural diurnal dissipation cycle of valley fog. Along the northern portions of the region, sea breezes dramatically increase cloudiness in the interior Motagua River valleys. Sea breeze moisture enters the Motagua Valleys through Puerto Barrios; narrow valleys with steep-sided slopes transport moisture 200-300 NM inland. Orographic uplift produces extensive cloudiness, but tops rarely exceed 12,000 feet (3,840 meters) with swift airflow funneling through to the interior. Bases are from 1,000 to 2,000 feet AGL (320-640 meters). Figure 3-26 shows low visibility patterns for two stations that lie along the western edge of sea breeze penetration. Visibilities of less than a mile correspond to the delayed entrance of moisture and distance traveled by Caribbean moisture.

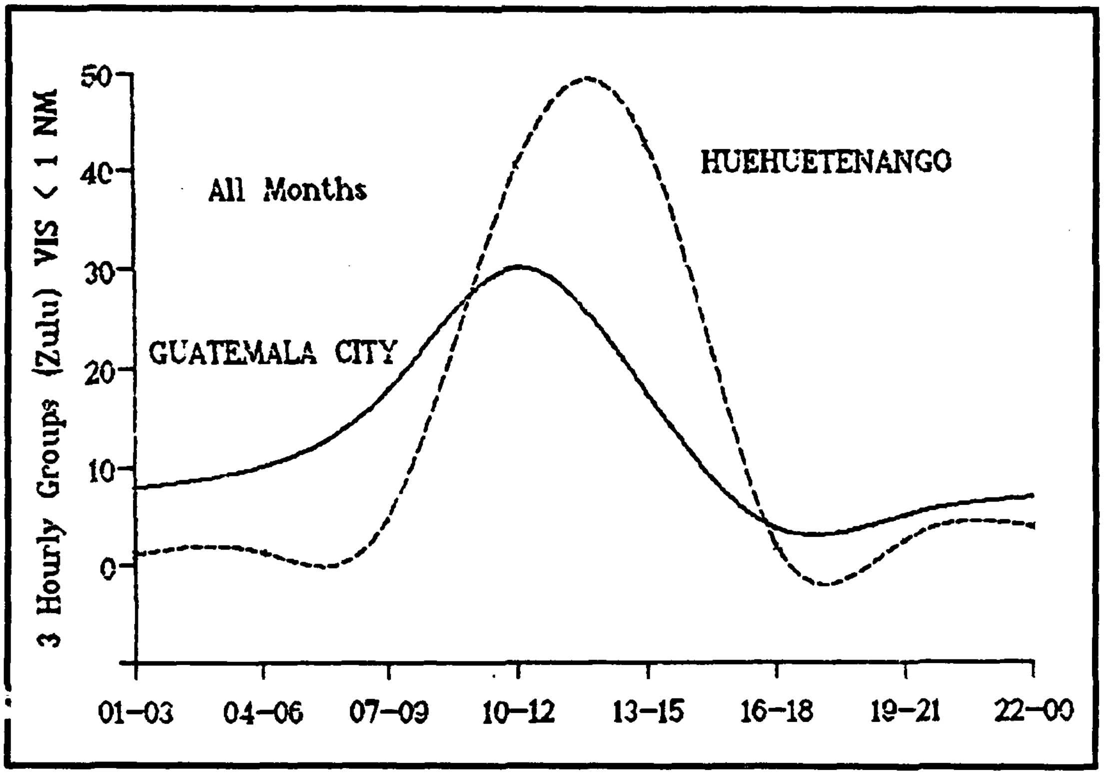


Figure 3-26. Visibility/Time Curves for Huehuetenango and Guatemala City.

WINDS. Prevailing winds at 5,000 feet (1,525 meters) during the wet season are from the northeast at 9-12 knots. Wind speeds in the higher elevations run 10-20 knots. The land/sea breeze circulation sets up onshore flow around 0830 LST, producing winds between 7 and 10 knots on the Atlantic coast. On the opposite (Pacific) side, the sea breeze is negated and speeds are lower, usually only 3-7 knots. The nocturnal land breeze on the Pacific side is between 7 and 10 knots.

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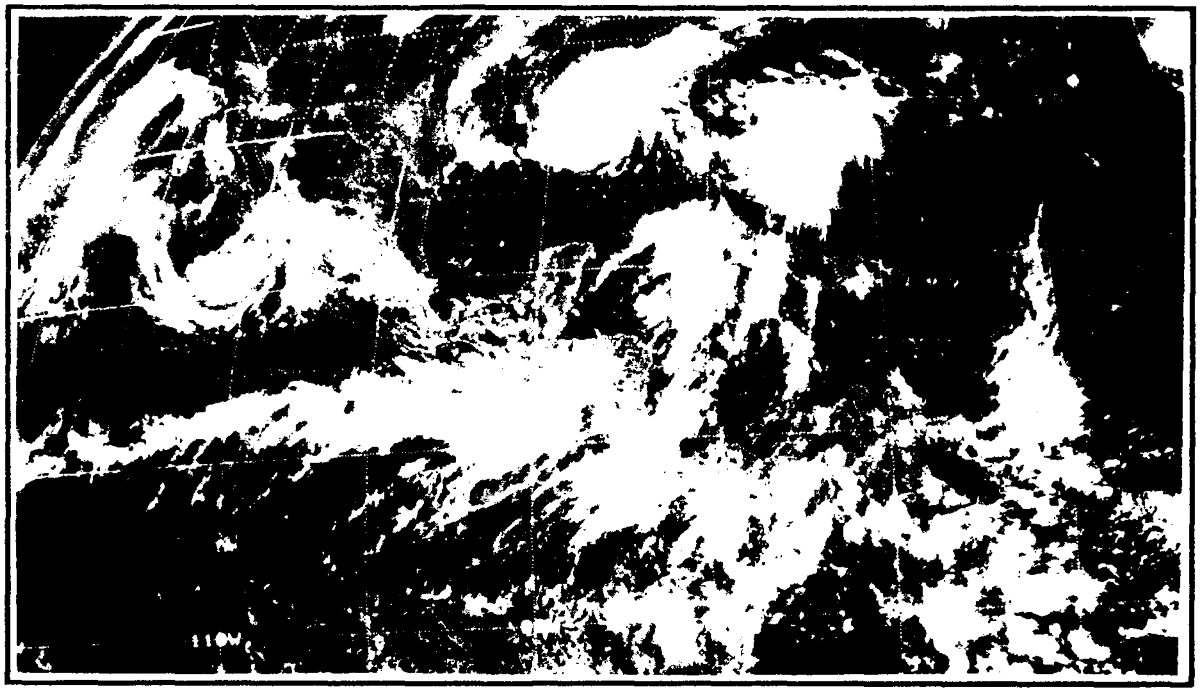


Figure 3-27b. Easterly Wave Enters the Northern Mountains. **Day 2:** The wave intensifies and moves onshore. Slow-moving convection over the mountains produces heavy rains.

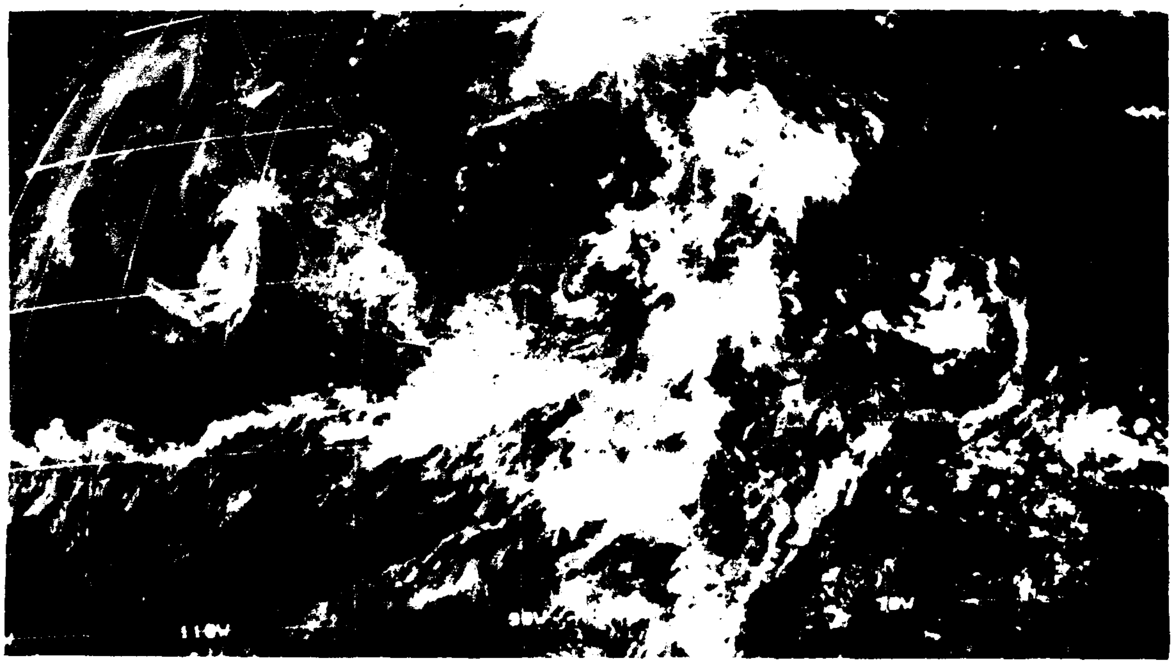


Figure 3-27c. Easterly Wave Stalls and Intensifies, **Day 3:** The complex interaction between the Monsoon Trough and the easterly wave is evident. Extensive cloudiness is fueled by Caribbean moisture and convergent low-level airflow.

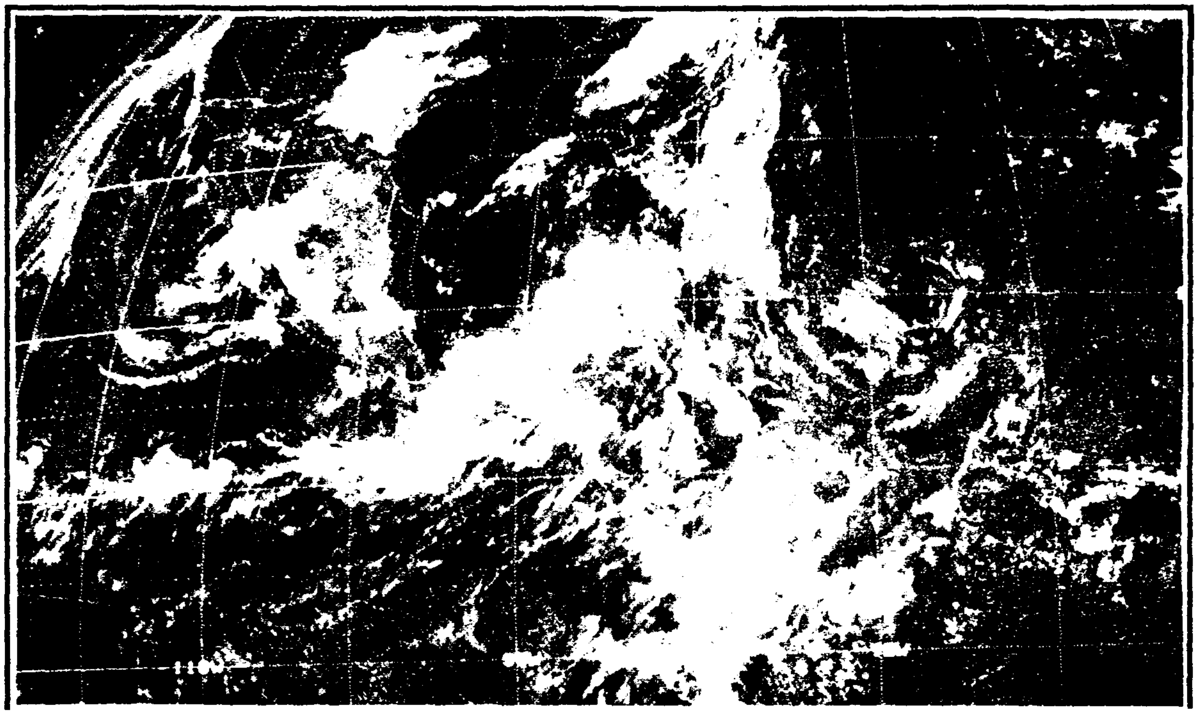


Figure 3-27d. A Chaotic Synoptic Disturbance, Day 4: The easterly wave is lost beneath a massive cloud canopy. Weak upper-level conditions allow the pattern to continue.

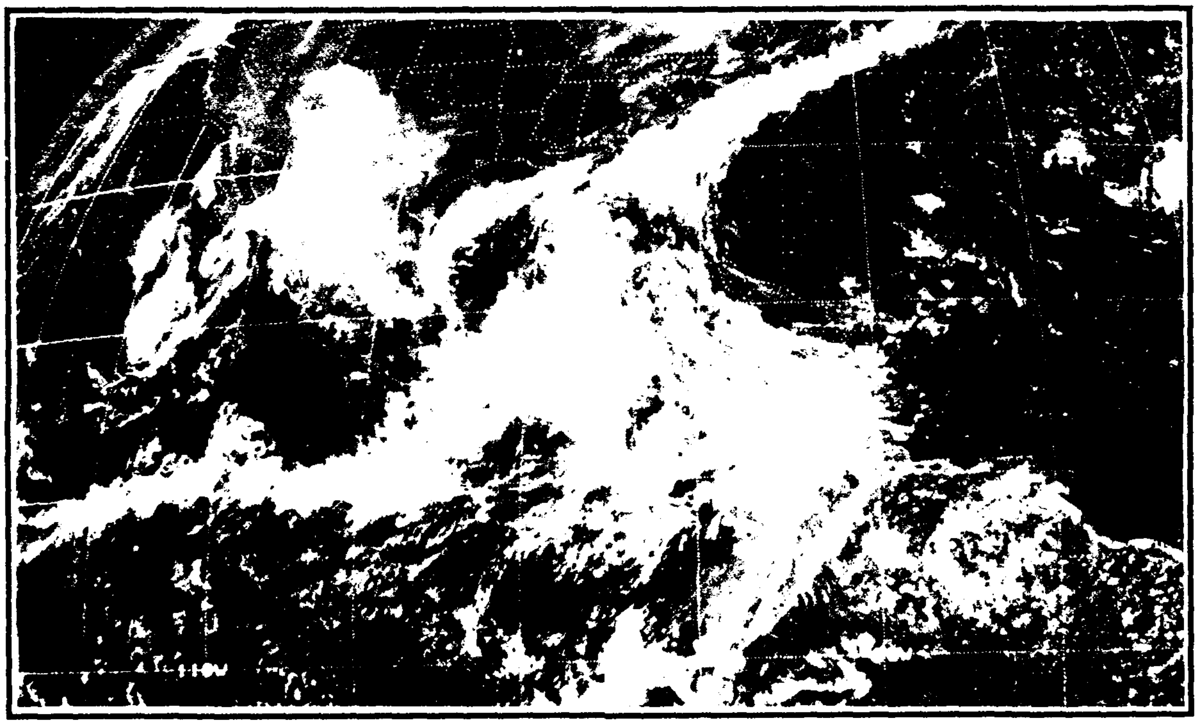


Figure 3-27e. The Disturbance Covers Entire Region, Day 5: The disturbance covers the entire region. The Monsoon Trough has maintained its position throughout the incident, as is usual.

PRECIPITATION. Mountain ridges perpendicular to the prevailing flow usually get more rain. Along the northwest sections of Guatemala near Finca Santa Teresa and Finca Moca Grande, for example, average annual precipitation exceeds 175 inches at the 3,000-foot (970-meter) level, but is only 30 inches farther inland at 7,800 feet (2,200 meters). The annual rainfall for Quetzaltenango is only 36 inches a year because of complex and rugged terrain that produces a "rain shadow" effect. The Motagua River Valley in Central Guatemala gets more than 110 inches a year because of the unrestricted flow of moisture from the Gulf of Honduras westward through Puerto Barrios. The Motagua Valley runs northeast to southwest and rises only 590 feet (180 meters) 100 miles inland from the Gulf of Honduras. It is surrounded by peaks higher than 10,000 feet (3,050 meters). In north-central Nicaragua, where lower terrain produces less uplift, rainfall amounts are between 50 and 70 inches annually.

TEMPERATURES. Mountain valleys with undisturbed airflow are slightly cooler during the day, but the general temperature regime is strictly a function of altitude. The wet season sees cooler daytime temperatures because of the increase in cloudiness. Average low temperatures in the highlands are between the low 60s °F (16-17°C) and the mid 70s °F (23-25°C). Highs rarely exceed 90°F and are usually in the 74-82°F (24-28°C) range. Only during a prolonged period of dry weather (such as with the "veranillo"), will temperatures rise. Clear nights with light winds produce radiation fog and drop lows into the 50s (14-16°C).

FREEZING LEVELS. The proximity of the Monsoon Trough during June and July results in increasing orographic uplift in this mountainous region; there is a marked increase in convection. Freezing levels across the region may drop by as much as 700 meters.

STANDING (MOUNTAIN) WAVES. Even the weakest of easterly waves can produce turbulence in the form of leeside mountain or gravity waves. Because of low clouds or clear skies during early morning hours, there may be no visual warning to an observer on the ground. The presence of an inversion is not necessary for the formation of a standing wave or the resulting turbulence.

MOUNTAIN VALLEY WIND FEATURES. In the Northern Mountains wet season, mountain slope insolation is considerably reduced due to increased cloud cover; lower temperatures result in weakened mountain/valley breezes. In the Motagua Valley, however, which lies parallel to the trade wind flow, winds are funneled and intensified by the venturi effect. Nocturnal mountain valley temperature inversions produced by the sinking of air along valley slopes produce radiation fog, especially in valleys isolated from persistent trade wind breezes. Cloudiness, mist, and fog also decrease the amount of sunshine and thermal energy necessary to dissipate moisture. Figure 3-28a shows typical valley wind system development at mid-morning during valley inversion breakup; Figure 3-28b shows the typical breakup sequence of a valley inversion.

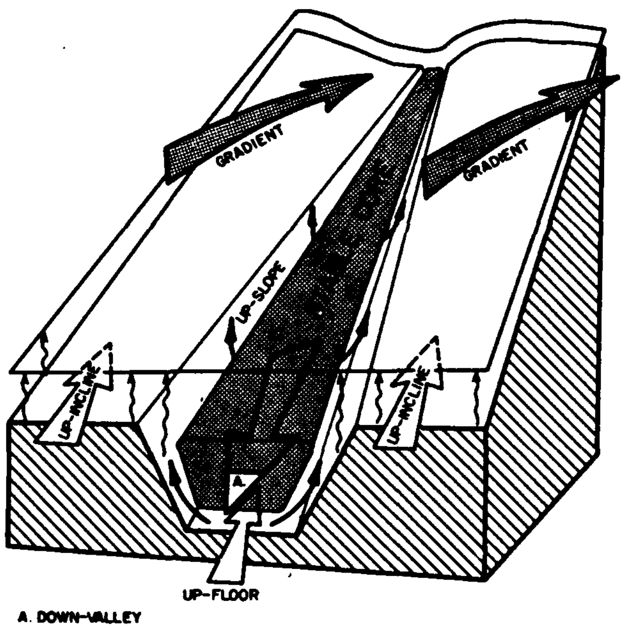


Figure 3-28a. Large Scale View of Valley Inversion Layer. The inversion is thickest at lower elevations due to gravity; locations near valley bottoms can expect persistent fog. Mountain valley inversions dissolve upslope first (from Whiteman, 1982).

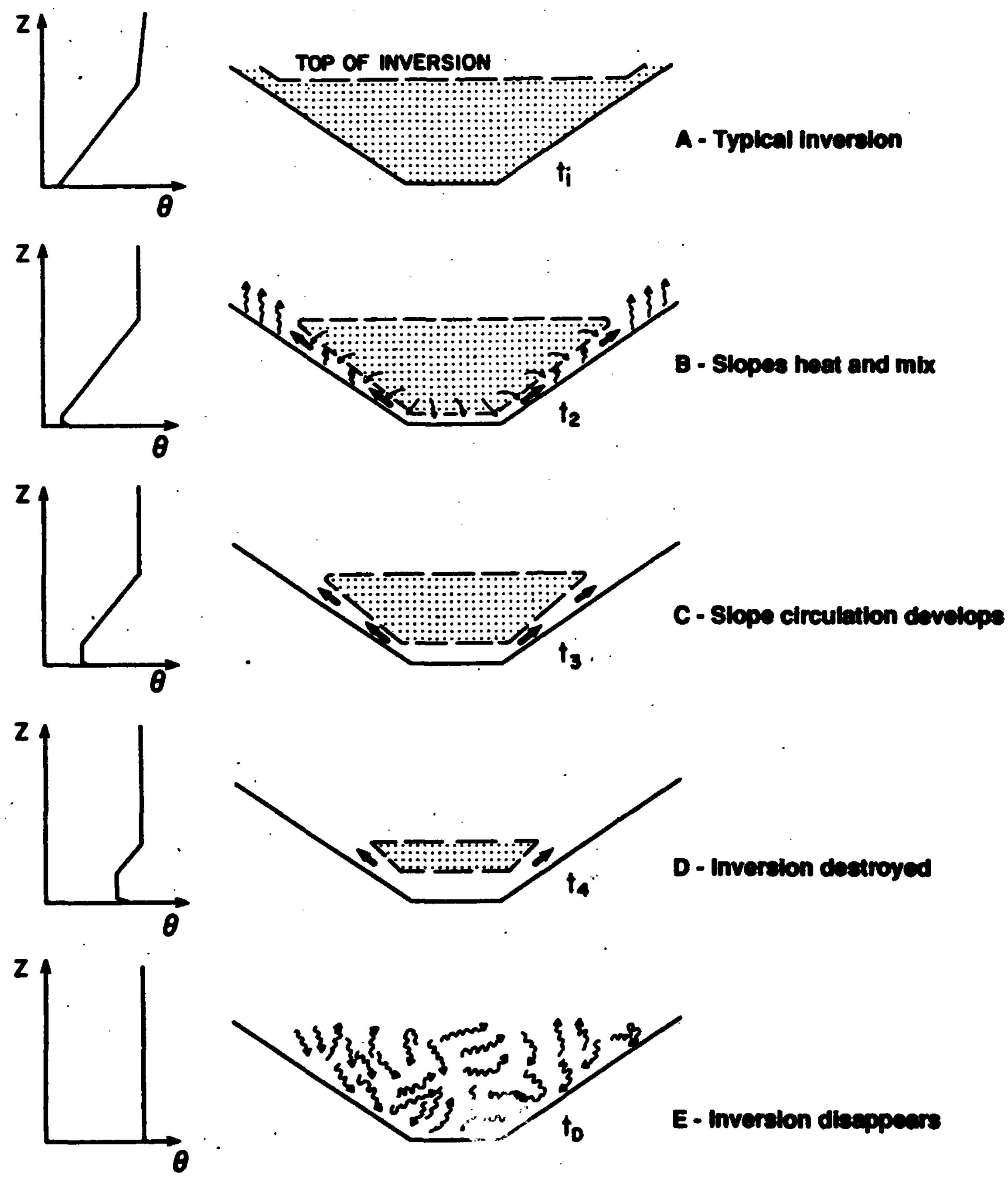


Figure 3-28b. Typical Valley Inversion Breakup. On the left, potential temperature (theta) versus height (Z). A is a cross-section of a typical inversion. B shows slope heating and mixing along the edges of the inversion. C shows mountain slope circulation developing by mid-morning. D is the destruction of the inversion. E is the final stage--the inversion disappears (from Whiteman, 1982).

GENERAL SENSIBLE WEATHER. The trade wind inversion and upper-level westerly flow (above 10,000 feet-3,050 meters) are the primary weather controls during the transition. Ocean moisture (from west and east) becomes trapped below the inversion. The inversion layer prevents moisture convergence, except along the lower terrain (below 4,800 feet--1,500 meters) of southern Nicaragua, where the two air masses frequently meet along the Monsoon Trough. Figures 3-29a and b illustrate convergence over lower, less complex terrain.

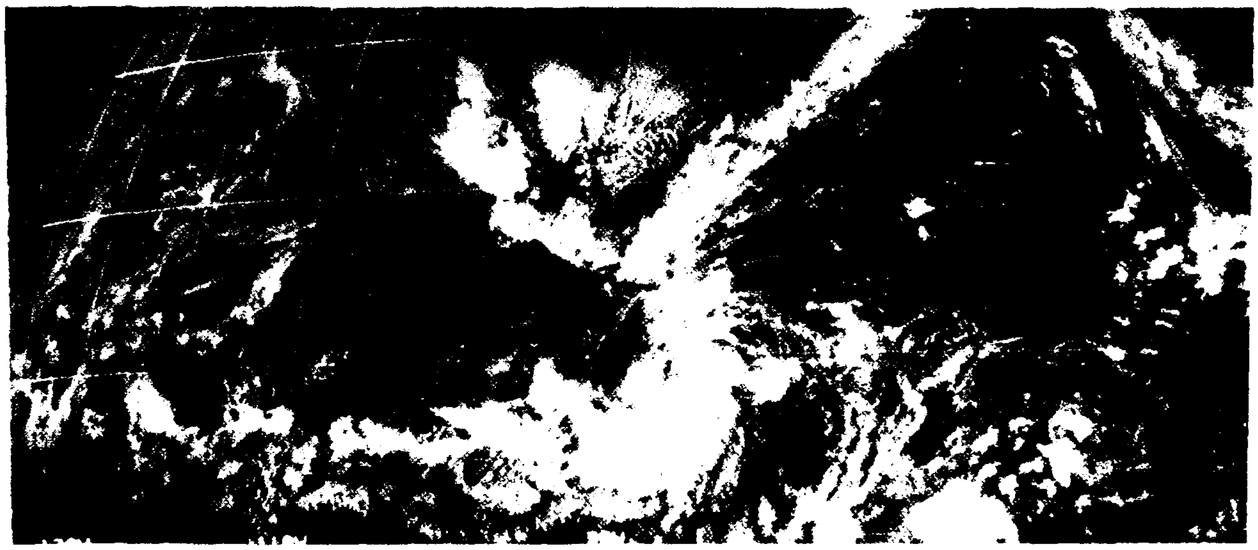


Figure 3-29a. The Normal Position of the Monsoon Trough During the Wet-to-Dry Transition. 14 November 1979 satellite imagery shows how Monsoon Trough convection (the thick cloud line) is normally located between 8 and 10 degrees north.

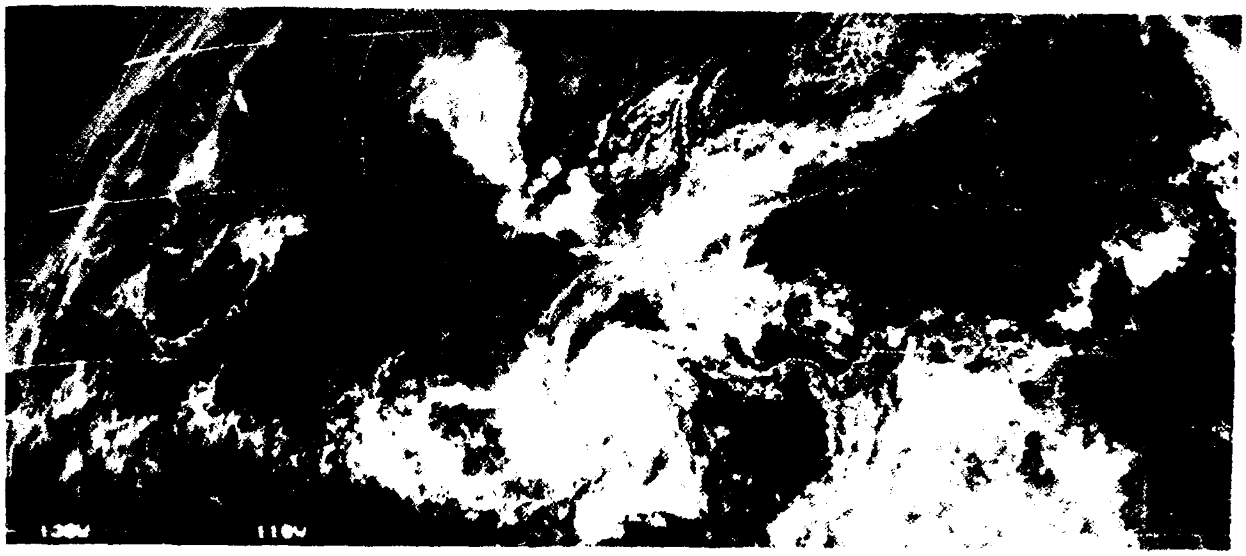


Figure 3-29b. Monsoon Trough Interaction with Passing Polar Front. This 15 November 1979 photo shows a cold front moving southward in the Northern Mountains and interacting with the Monsoon Trough to produce extensive thundershowers. To the southwest (at 10 degrees N, 90 degrees W) the two synoptic features combine to form a hurricane.

SKY COVER. The Gulf of Honduras and its coastlines are at their wettest period of the year. There is low-level stratus and mixed cumuliform cloudiness along the coasts and inland to the west where moist currents prevail. Bases range from 1,500 to 2,500 feet (500-850 meters) MSL. The rest of the region sees a gradual decrease in humidity and upper-level moisture. Mid-level stratiform cloud and some terrain-induced cumulus with tops to 10,000 feet (3,050 meters) are found along windward slopes. In November, mean sky cover decreases from about 75 percent to about 60 percent. At Guatemala City, sky cover drops from 75 to 54 percent; at Tegucigalpa, from 79 to 69 percent. At San Pedro Sula and Tela, which are still relatively "wet," mean sky cover drops from 82 to 73 percent, and from 72 to 67 percent, respectively.

WINDS. Prevailing wind direction during the transition period is northeast. The inversion limits the vertical extent of this flow to 6,000 to 10,000 feet (1,900-3,050 meters). Above 10,000 feet, moderate westerly flow dominates to 20,000-30,000 feet (6.2-9.4 km). A periodic mid-latitude intrusion can bring winterlike conditions to the highlands. Bitter winds out of the north can reach 20 to 30 knots and lower temperatures into the fifties. The onset of these "Nortes" signals the transition from wet to dry conditions.

PRECIPITATION. By November, most Northern Mountains locations are getting only half the rainfall they got in October (Guatemala City about six times less, Quetzaltenango ten times less, and Tegucigalpa three times less). But there is much heavier rainfall at coastal locations along inland valleys that allow the funneling of moist easterly low-level flow. At La Ceiba, Trujillo, and Tela, for example (all on the northern coast of Honduras), there is more rain in November than in October; in fact, the so-called "transition" season here is more of a "wet" season, and is when maximum monthly rainfall occurs.

TEMPERATURES. Average temperatures remain mild. The northern coast at La Ceiba sees highs near 82°F (28°C) and overnight lows of 70°F (21°C). Inland, at San Pedro Sula, daily highs and lows average 85°F (29°C) and 68°F (20°C). In general, increases in elevation increase the daily temperature range because of drier winter air.

GENERAL WEATHER. The most important dry season weather feature is the strengthening trade wind inversion. Moist low-level easterly flow ascends the Caribbean slopes to condense and evaporate quickly within the inversion layer. This process releases latent heat and produces dry, warm easterlies to western (leeward) sections. Only polar surges (one to four a month) disrupt the pattern.

Figure 3-30. A Strong Polar Intrusion. In this 21 January 1979 photo, cloud streaks illustrate the ability of westerly flow to shear polar surges in the tropics. More intense fronts remain intact over northern parts of the region,where they produce frontal type showers.

SKY COVER. Fog, with low ceilings and visibilities, occurs daily in some mountain valleys above 6,000 feet (1,850 meters). Other valleys see shallow cumulus, generated by the differential heating of mountain slopes, that rarely reach above 10,000 feet (3,050 meters) due to subsidence aloft. Individual valley orientation to wind and sun produce local anomalies in undisturbed conditions. The highest frequencies of ceilings below 3,000 feet (915 meters) occur during the height of polar intrusions along the northern Honduran coast. Slightly higher frequencies occur during daylight hours because of the assistance provided by sea breezes. Figures 3-31a and 3-31b for San Pedro Sula, Honduras, show the highest percentages of occurrence for ceilings below 3,000 feet (915 meters) and visibilities below 1 nautical mile in the dry season.

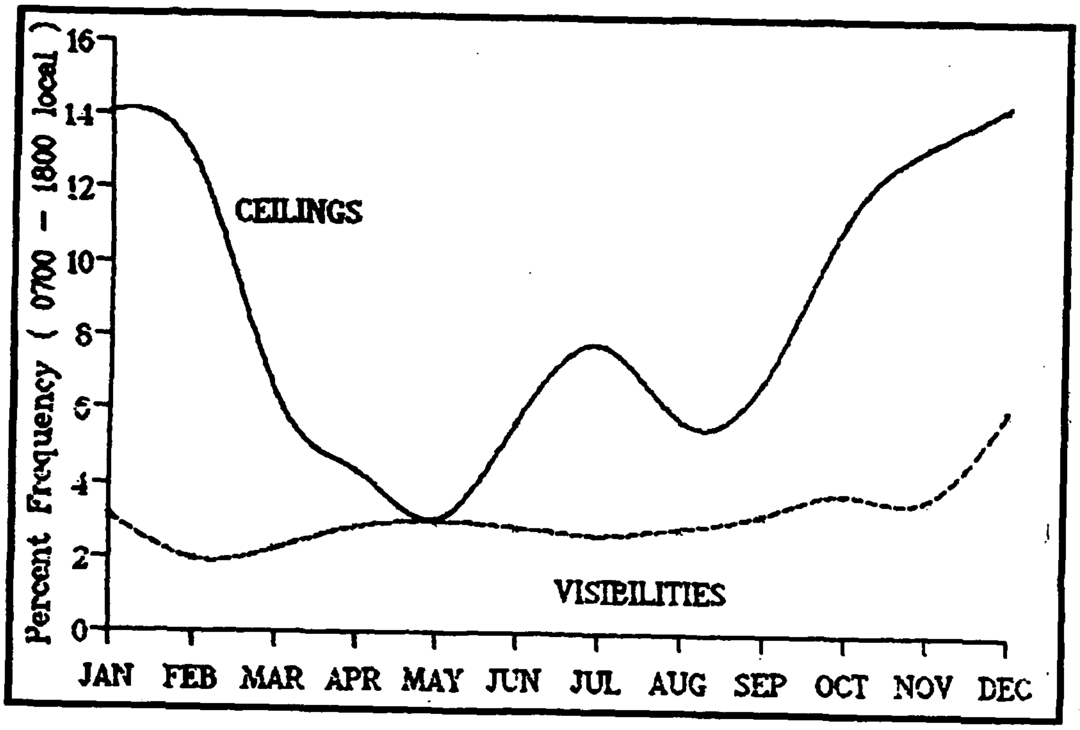


Figure 3-31a. ***Daytime*** **Frequencies of Ceilings Below 3,000 Feet and Visibilities Below 1 Mile for San Pedro Sula, Honduras.**

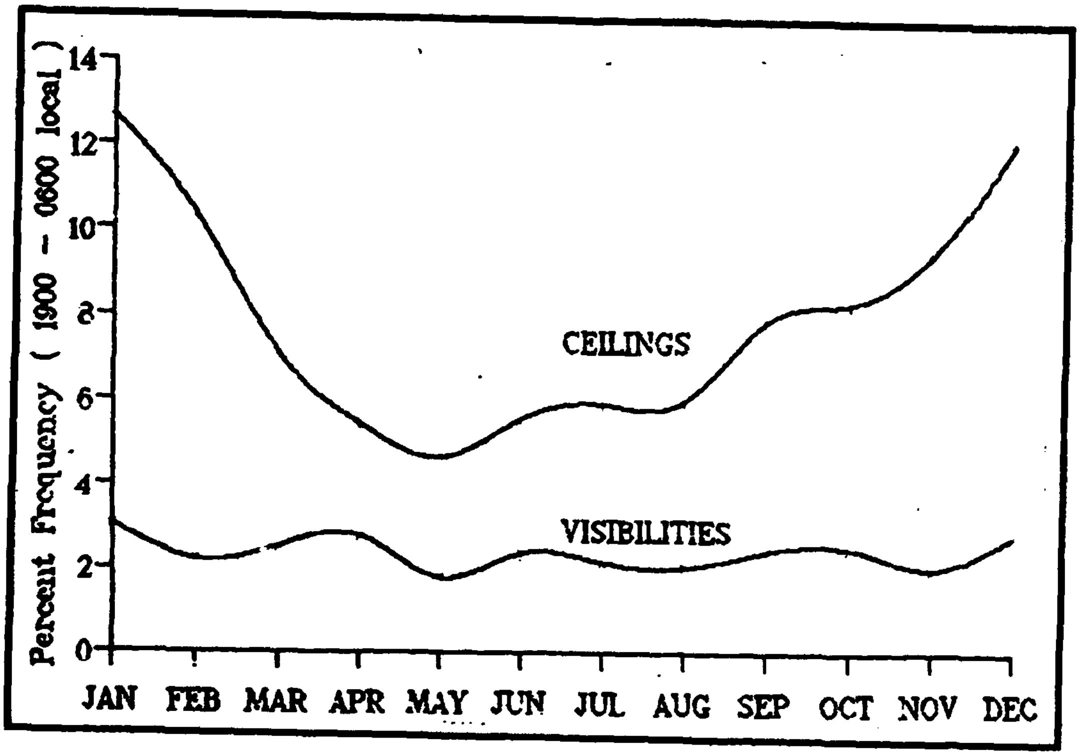


Figure 3-31b. ***Nighttime*** **Frequencies of Ceilings Below 3,000 Feet and Visibilities Below 1 Mile for San Pedro Sula, Honduras.**

WINDS. The prevailing northeasterlies are temporarily replaced by cold fronts moving out of the United States. Winds behind the front are northwesterly, but vary locally in valleys. Gusts may reach 40-50 knots. Mean upper-level winds are northerly during the dry season. Mountain wave and clear air turbulence (CAT) are often associated with closely packed isotherms at 300 millibars. Studies show that the greatest probabilities for CAT are ahead of the bases of large amplitude troughs, with frequency directly proportional to the strength of westerly flow. Here, CAT occurs most often between 35,000 and 43,000 feet (10,500-13,400 meters). CAT is more severe along the lee sides of mountain ridges than near individual peaks. Mountain waves are usually found below the inversion layer. A steep temperature gradient or strong inversion strengthens the mountain wave. The Caribbean ranges of central and northern Nicaragua are likely source regions for mountain waves.

TEMPORALES. Conditions for formation of the temporale along the Gulf of Honduras are favorable. Normally forming over moist ocean shallows, these systems produce hurricane-type rainfall, but without hurricane winds. The extremely heavy rainfall persists for periods of 24 to 36 hours. Stagnating cold fronts shear at higher levels and form cutoff lows at the surface. Low-level convergence from the easterly surface flow tends to induce cyclonic turning of moist air into the area of low pressure.

PRECIPITATION. March and April are normally the driest months of the Northern Mountains dry season. Because winter is the driest season and the highest peaks lie above the inversion, snow rarely accumulates. The western parts of the Northern Mountains are very dry in winter; eastern portions are wetter. An exception is along the northern Honduran coast where winter is the wettest season. The topography of the northern coast of Honduras (from La Ceiba to Trujillo), along with synoptic weather patterns, results in anomalously wet winters in this area. The entire northern coastline, oriented west-to-east, is backed by extensive coastal ranges and lies below the trade wind inversion. The mountain ranges provide orographic lift for nearby Gulf of Honduras moisture. In winter, synoptic airflow is north to northwesterly. The moisture flow lifts orographically, producing continuous rain showers. The trade wind inversion confines moisture to the adjacent coastal plain. The land/sea breeze, reinforcing onshore flow by day and producing convergence lines by night, produces drizzle and showers at any time of day. Adding to the rainfall anomaly here is the fact that frontal activity is frequent during winter. Polar surges pick up Gulf moisture before crossing the coast. This moisture further increases rainfall potential as it climbs the coastal ranges. Orographic precipitation from low-level stratus is normal on immediate coasts. Inland, orographic uplift produces cumulus on windward slopes and clearing skies on leeward sides. Polar intrusions can carry instability several hundred miles into the interior, where air rides up and down over successive ridges. As air descends the first ridge, it loses some of its moisture. It is lifted over the second and successive ridges until all the moisture is gone. Rainfall can be heavy, particularly if one of these systems stagnates.

TEMPERATURES. Air temperature here is usually a function of altitude rather than of latitude. Winter's dry air provides a large diurnal temperature range, but at times a high incidence of fog can decrease that range. At Quetzaltenango (elevation 7,806 feet or 2,380 meters), nighttime lows average 34-38°F (1-2°C); daytime highs are from 68 to 77° F (20-24°C). At Guatemala City (elevation 4,885 feet/1,490 meters), average lows are 54-58°F (11-13°C); highs are in the 73-80°F (22-25°C) range. At San Pedro Sula (elevation 280 feet/85 meters) on the north coast of Honduras, lows average 64-68°F (18-20°C), highs 85-92°F (30-33°C). The "Norte," which can begin as early as October, doesn't affect temperatures here until December. Thermal gradients behind fronts rarely drop the temperature by more than 3 to 5°C.

GENERAL WEATHER. The overlap between the December-April dry season and the March-May dry-to-wet transition results form large variations in trade wind inversion strength over this vast area. A weakening trade wind inversion, deep northeast trade wind moisture, and the Monsoon Trough combine to control the transition weather pattern. Persistent low-level convergence produces heavy shower activity in southern sections along the Monsoon Trough, while orographic uplift against the Caribbean (windward) slopes is reponsible for large-scale convection in the north and east.

SKY COVER. Along the northern Honduran coast, sky conditions improve slowly. Most other locations are exposed to early morning fog, smoke, and haze. Cloud tops over the eastern half of the region begin to reach 15,000-18,000 feet (4,600-5,500 meters) as the inversion layer's thickness and temperature gradients decrease. Bases are typically 2,000-3,000 feet (610-915 meters) with scattered cumulus along ridges. Polar intrusions lower bases to 1,000-2,000 feet (330-610 meters), with cumulus embedded throughout stratus decks. Monsoon Trough surges produce high cirrus canopies that precede the eventual isolated thunderstorm activity. Turbulence along the Monsoon Trough is light to moderate; icing is possible in tops above 30,000 feet (9,125 meters).

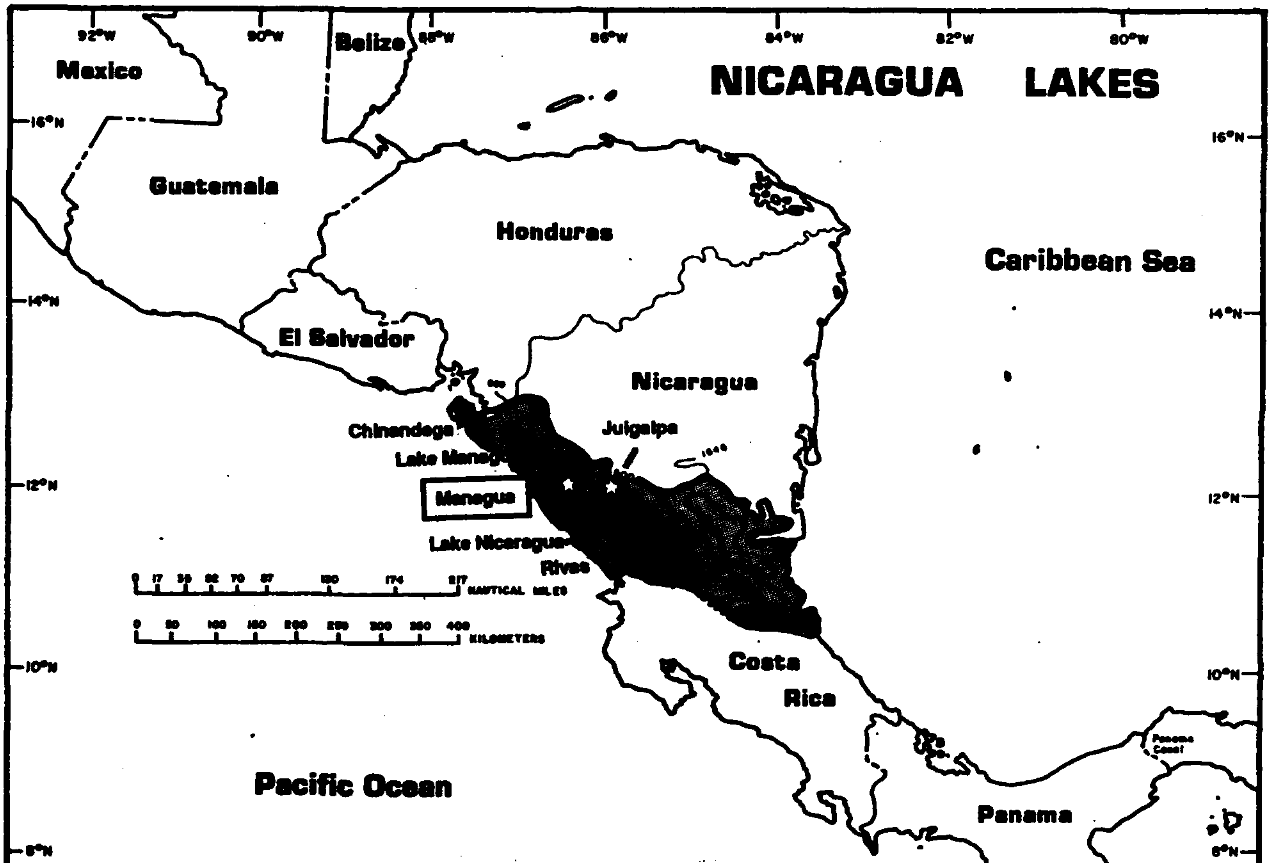
WINDS. Early in the transition, wind speeds are strong because of the influence of the 500-millibar anticyclone. Predominantly northeasterly, a "Norte" can provide brief periods of north and northwest surface flow. Mountain and valley currents are strongest in the high sun periods of April and May, especially in the north.

THUNDERSTORMS. Commonly associated with the rare northward surge in the Monsoon Trough, thunderstorms orient themselves west-to-east over southern sections of the Northern Mountains. Surges of these cross-equatorial breezes touch off large clusters of convection. With the inversion virtually nonexistent over the Pacific, tops can reach 45,000 feet (13.5 km). Lightning and hail are rare, but orographic uplift may increase the severity of the disturbances.

PRECIPITATION. By May, vertical instability begins to increase. May rainfall averages more than 4 inches (102 mm) everywhere except on the highest peaks and along the north Honduran coast.

TEMPERATURE and relative humidity increase throughout the period. Diurnal ranges, however, decrease as moisture in the upper levels increases. Highs average between 82 and 93°F (28-33°C). The highest temperatures are at coastal locations.

3.5 THE NICARAGUA LAKES



MANAGUA/SANDINO:NICARAGUA

	EXT MAX	MEAN TEMP	EXT MIN	AVG MAX	AVG MIN	TSTM DAYS
JAN	95	79	60	88	68	.2
FEB	95	80	62	90	69	.3
MAR	99	82	63	92	71	.3
APR	100	84	67	94	73	1.6
MAY	99	84	69	93	75	7
JUN	95	81	68	88	74	10
JUL	95	81	68	88	73	8.5
AUG	98	81	69	88	73	8.9
SEP	95	80	68	88	73	14.7
OCT	93	80	68	88	72	10.8
NOV	92	79	60	88	70	3.7
DEC	93	79	60	88	69	.2

Figure 3-32. The Nicaragua Lakes. This region runs northwest to southeast from the Gulf of Fonseca across coastal Nicaragua along the 500-foot (150-meter) contour, then straddles the Nicaragua-Costa Rica border to end between San Juan del Norte and Puerto Limon on the Carribean coast. A climatic summary for Managua/Sandino is inset.

NICARAGUA LAKES GEOGRAPHY

Lake Managua and Lake Nicaragua dominate the region. Lake Nicaragua, the larger of the two, is about 100 feet (30 meters) above sea level. Except for a string of volcanic cones that run through the area from the Gulf of Fonseca to the approximate center of Lake Managua, the region is relatively flat. Several volcanic cones rise from the surface of Lake Nicaragua. The largest of these, at Altagracia, is 5,285 feet (1,611 meters) MSL. It has erupted since 1800. The city of Managua and its Augusto Cesar Sandino International Airport (194 feet--59 meters) lie on the southernmost shore of Lake Managua.

Several unique geographic features of the lakes region have a dramatic effect on its weather:

First, the large water expanses of the lakes: although Lake Nicaragua (with about 4,000 sq miles--10,240 sq km) dwarfs its northern neighbor Lake Managua (about 500 sq miles--1,280 sq km), both are significant moisture sources. The lakes are connected by a small river which helps keep both elevations just over 100 feet (30 meters) above sea level.

Second, the terrain here is relatively flat with elevations between 100 to 200 feet (30 to 60 meters). But there are isolated groups of mountains that top 5,000 feet (1,525 meters), including volcanic cones that protrude from the surface of Lake Nicaragua. There is also a small range of mountains in the narrow strip of land between the lakes and the Pacific Ocean. The tops of these hills are between 2,000 to 3,000 feet (610 to 915 meters).

Finally, there is the Marabios Range, located between the northern shore of Lake Managua and the Gulf of Fonseca. This range is oriented northwest-to-southeast with a maximum elevation of 5,725 feet (1,745 meters).

A flat expanse of land between Lake Nicaragua and the Caribbean is an ideal drainage basin for rivers flowing from the mountains on either side. The terrain to the south rises rapidly to peak at over 10,000 feet (3,050 meters) in central and southern Costa Rica. The mountains to the north are much smaller, with tops between 1,500 to 2,000 feet (455 to 610 meters). Rivers crisscross the entire region, with swamps and marshland along the southern shore of Lake Nicaragua and another stretch near the Caribbean.

Evergreen forests predominate outside the swamplands. Nicaragua makes use of the terrain on the eastern shore of Lake Nicaragua for farming, using irrigation to create extensive rice paddies.

GENERAL WEATHER. The Monsoon Trough and the southwesterly flow associated with it are the primary wet season weather features. Moist southwesterlies off the Pacific push onshore and fuel the diurnal convective cycle. Showers and thunderstorms are daily occurrences.

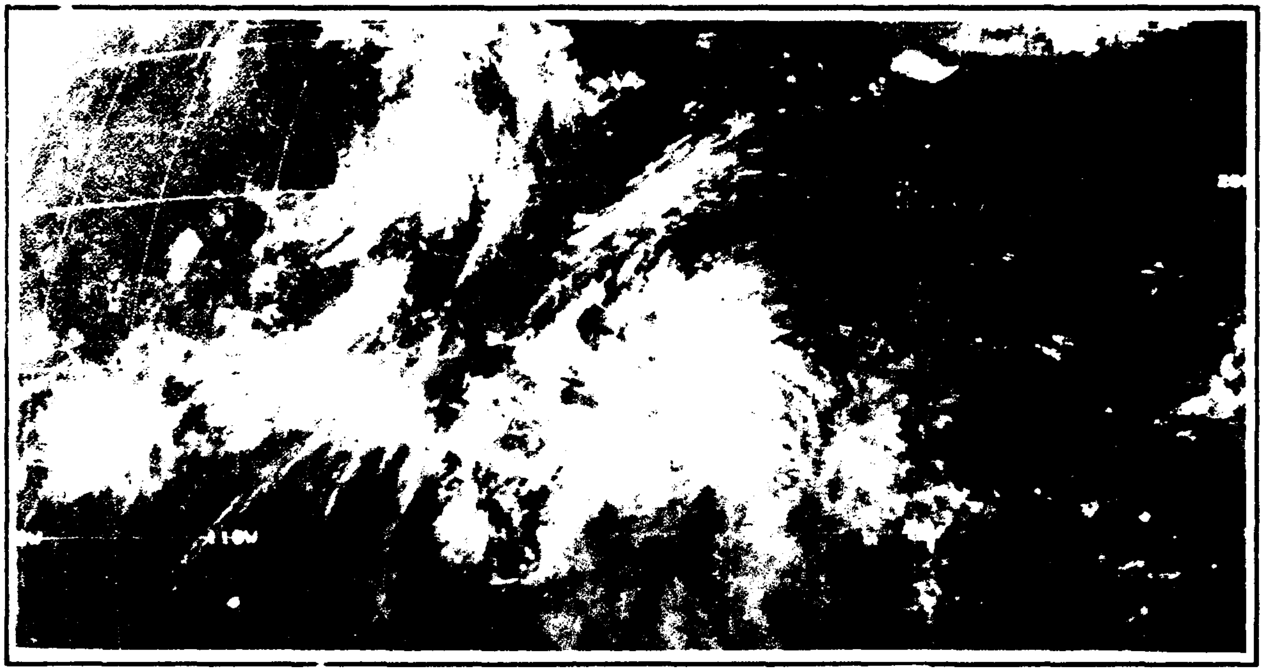


Figure 3-33a. Convection Develops in Association With the Northerly Surge of Southwesterly Flow. In this 12 July 1976 photo, large-scale convection develops over open water north of the Monsoon Trough.

Figure 3-33b. The Disturbance 24 Hours Later. The large cloud cluster's movement is controlled by onshore flow.

The Monsoon Trough oscillates diurnally, moving onshore by day and receding over water by night. Figure 3-34 shows heavy convective activity poised offshore. At photo time (1100 LST), the sea breeze was not yet at full strength, but it would eventually push the entire line over land.

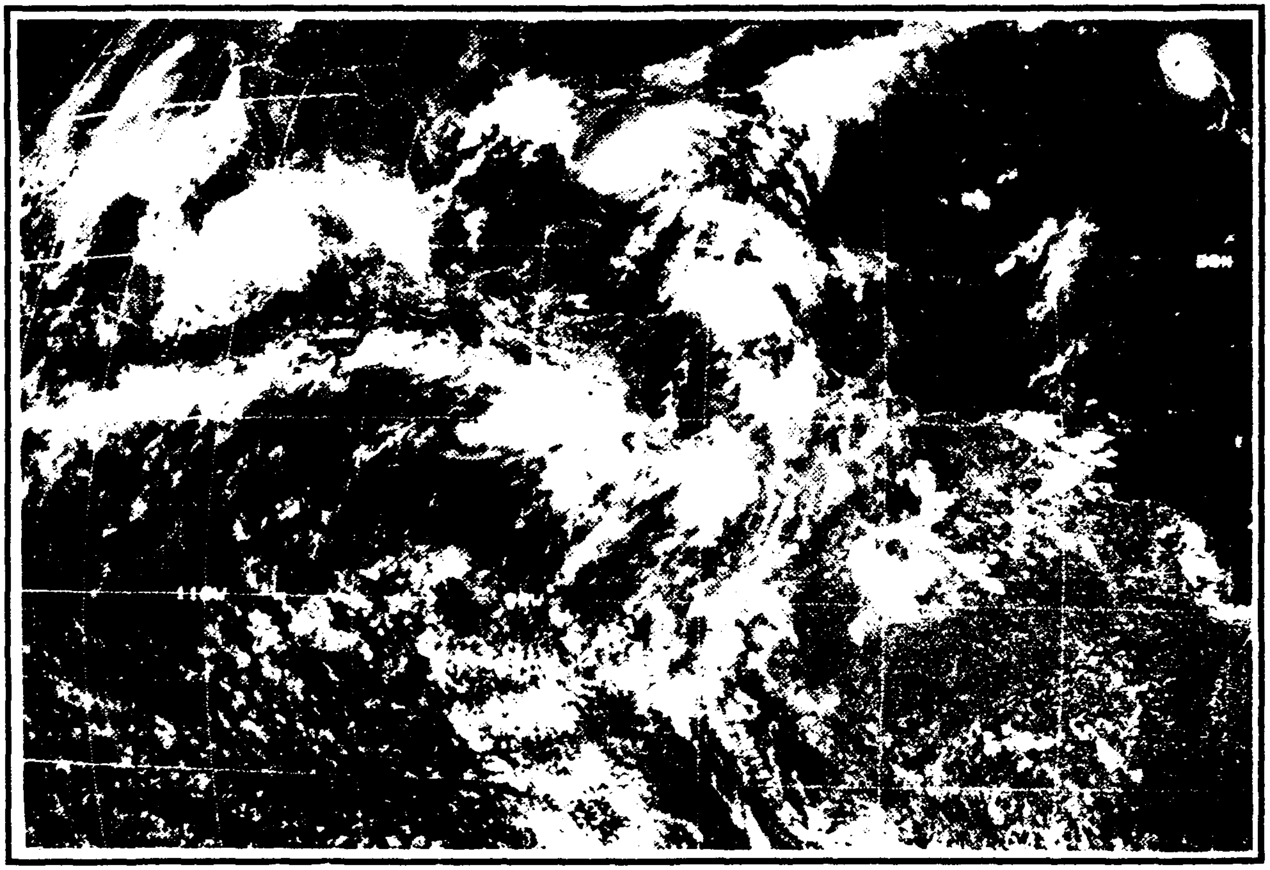


Figure 3-34. Nicaragua Lakes' Effect On Convective Activity. In this 11 September 1979 photo, notice the narrow ring of cloud-free sky along Lake Managua's rim. Surface data might indicate some mesoscale divergence in the low-level wind profile.

SKY COVER. Diurnal sea breezes generate trade wind cumulus until 1600 LST. Mornings average 3 to 5/8ths sky cover with bases between 1,500 and 2,500 feet AGL (460-765 meters). In the south and nearby mountains, Caribbean moisture forms bases at 1,000-1,500 feet (330-460 meters); higher terrain is obscured. Embedded thunderstorms are found in solid stratocumulus decks with 3,000-foot (915-meter) bases. In the northern sections there is a complex interactive cycle between diurnal convection and lake breezes. Cloud cover remains less than 2/8ths until 1100 LST before the diurnal heating cycle reverses the lake breeze. By 1200 LST, convective cells are between 6,000 and 12,000 feet (1,830-3,660 meters). Visibilities rarely fall below 6 miles but they can go below 4 miles in early morning haze or heavy rain. In Figure 3-35, lower cloud bases are shown for Juigalpa, a location dominated equally by Caribbean and Pacific moisture. Juigalpa is located near the windward (Pacific) slopes of the Northern Mountains; orographic uplift causes the increased frequency of low ceilings in midsummer.

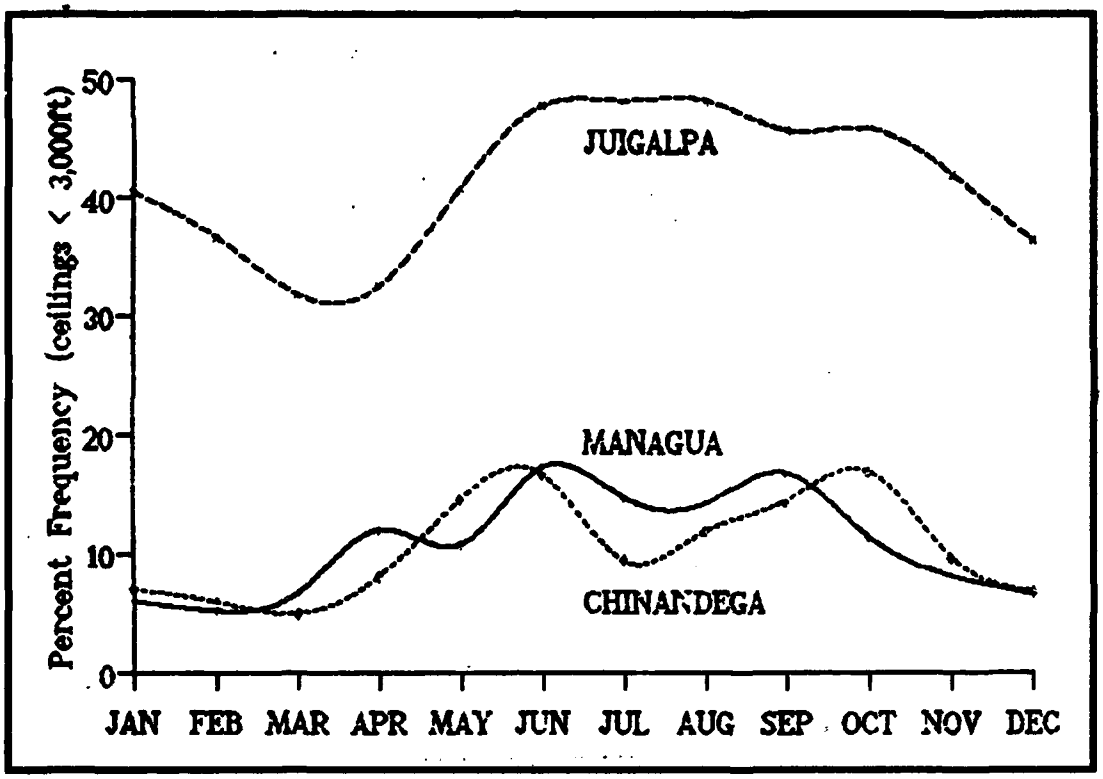


Figure 3-35. Ceiling Frequencies Less Than 3,000 feet For Three Nicaragua Lakes Locations.

WINDS. Trade winds are generally light, averaging 5-10 knots. The lakes proper, however, have their own localized wind structure caused by the diurnal lake breeze effect. Prevailing winds at Managua are easterly at less than 10 knots. In the isthmus between the lakes, however, speeds increase to 11 or 12 knots. At night around the lake, onshore flow produces steady breezes varying from the prevailing northeast flow but rarely exceeding 8 knots.

THUNDERSTORMS. The convergent low-level flow over the southern part of the Lakes region produces numerous severe thunderstorms, many with gusty winds and 3/4" hail. Rivas, Nicaragua, south-southwest of Managua, sees an average of 12 such severe storms a year, most between August and October. Strong low-level convergence from the Monsoon Trough, interacting with northeasterly flow, builds large convective towers that reach to 42,000 feet (12.8 km) or more.

PRECIPITATION. Although the lakes provide additional moisture to locations downwind of the prevailing flow, heavier precipitation downwind is not evident. The southernmost fringes of the region are in the direct path of flow off the Caribbean. These sections are extremely wet and get more than 85 inches (2,160 mm) of rainfall a year. Most of the rain in the south falls as the result of convective activity between 1200 and 1800 LST. Normal wet season weather, however, consists of diurnal convective thundershowers between 1500 and 2200 LST. In the interior, nocturnal thundershowers are common, thanks to localized wind regimes and topography to the east. Most thunderstorm activity results from the convergence of flow off the Caribbean and the sea breeze off the Pacific. Cells regularly propagate northwestward into Nicaragua from Costa Rica. As these cells move out over the lakes, redevelopment depends on the strength of the dry mountain winds from the east and the dynamics of the lake breezes themselves. In the northern half of the region, divergent flow produces an annual rainfall averaging only 35 to 50 inches (809 to 1,270 mm). Here, too, localized convective cells are the primary weather producing systems.

TEMPERATURE. Wet season mean daily highs drop from 91-95°F (33-35°C) in May to 87-90°F (31-32°C) by July. Temperatures in urban Managua are 2-5°F (1-2°C) higher due to the heat island effect, but nocturnal breezes off Lake Managua bring relief. Low temperatures are a function of proximity to water; locations near the lake stay near 74-75° F (23-24°C), while those farther from the lake's modifying breezes are in the upper 60s °F (20-21°C).

GENERAL WEATHER. Increasing subsidence aloft (above 700 mb) and the tradewind inversion are the primary weather controls during November. Upper-level westerlies produce subsidence aloft as well as drier air, and act as the steering mechanism for active polar surges. The trade wind inversion intensifies at 5,000-6,000 feet (1,600-1,830 meters), causing descending northeasterly tradewind flow into the region to warm and dry adiabatically, significantly dampening the diurnal convective cycle. Polar surges and remnants of tradewind surges (in the Monsoon Trough) temporarily disrupt the inversion and subsidence aloft. Figure 3-36 shows the typical cloudiness/weather associated with a polar surge.

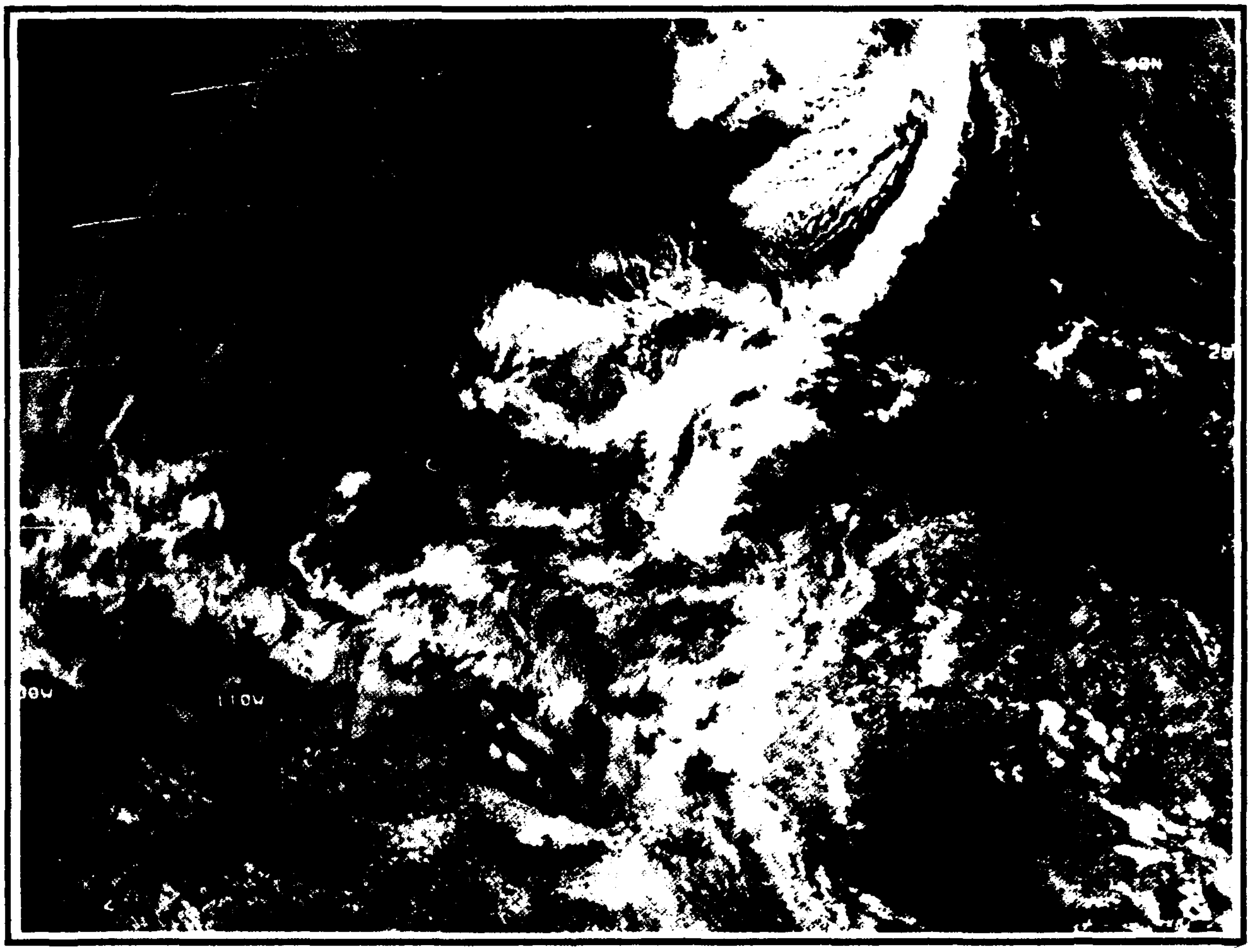


Figure 3-36 The Pacific Influence on a Polar Surge Into the Lakes Region. Sea breezes pump low-level, Pacific moisture into this 14 November 1975 disturbance. Without an inversion to cap convection, isolated thundershowers develop. Cloudiness and rainfall rarely persist for more than 24 hours. Typically, northeasterlies reestablish, with lee side dry air dissipating the convection.

SKY COVER. Bases average 2,000-3,000 feet (610-915 meters) but rarely exceed 10,000 feet (3,050 meters) in the northern third of the Lakes region. Tops may reach 20,000 feet (6.2 km) in the south, where greater instability results from moist Caribbean and Pacific airflow.

WINDS. Winds are normally northeasterly, but localized winds on the lakes vary in direction. Speeds are normally 8 to 12 knots, greater along the leading edges of frontal incursions. Downslope breezes caused by the stronger trades can reach 20 knots or better in the absence of cloud cover.

PRECIPITATION. November rainfall averages 2 to 3 inches (51-76 mm) throughout the Lakes region. There may be showers from shallow convective cells in late afternoon. The increased inversion strength and stronger northeasterly flow limit vertical development over flat terrain, but orographic lifting may let individual cells grow to 20,000 feet (6.2 km) and spread precipitation downwind.

TEMPERATURES. The Lakes region averages 4 days a month during which temperatures are above 90°F (32°C). Lows rarely dip below 68°F (20°C), and then only at high elevations with the passage of a cooler mid-latitude front. Sea temperatures are still high enough to moderate lake and ocean locales. Daytime highs average 86°F (30°C); lows about 75°F (24°C).

GENERAL WEATHER. Upper-level westerlies, the trade wind inversion, and polar surges are the three primary winter dry season weather controls. Upper-level westerlies bring dry, subsident air aloft; but one to five times a month, the westerlies carry weak troughs into the region, along with light showers. The trade wind inversion, however, forces the prevailing northeasterly flow downward into the region, where it becomes adiabatically dry, rather than moist.

SKY COVER. The diurnal convection cycle is dampened by the combined effects of the inversion and strong adiabatic leeside drying. Clouds are most common at night, with the lakes providing the moisture. Sky cover at dawn is 3/8ths with bases at 2,000 feet (610 meters); visibilities are between 3 and 6 miles. By late afternoon, sky cover decreases to 1/8th; visibilities are greater than 6 miles. Sky cover rarely exceeds 2/8ths; bases are rarely lower than 3,000 feet (915 meters). Early mornings occasionally see fog forming where topography serves as a wind break and radiation cooling is favorable.

WINDS. The strongest mean wind speeds (9-12 knots) are observed in the dry season. Prevailing direction is northeasterly in the lower 10,000-15,000 feet (3,280-4,600 meters, but above 15,000 feet (4.6 km)), persistent westerlies average 25-40 knots. Along the eastern fringes of the Lakes region near mountain slopes, winds can gust to 40 knots in advance of stronger polar intrusions.

PRECIPITATION. Rainfall averages less than 1 inch (25 mm) a month from December to April, except for the extreme southeastern corner near the Nicaraguan-Costa Rican border. The Lakes region proper is isolated from Caribbean moisture by the interior mountains, and the persistent trade winds descend into the region as dry adiabatic flow; dry season precipitation is scant. Polar surges provide an isolated shower every 7 to 10 days.

TEMPERATURES. Peak insolation occurs in April, when skies are clearest. As a result, highs of 90-95°F (32-35°C) are observed in April and May. The average low is 75°F (24°C). Winter temperatures are normally in the upper 70s °F (25-27°C) and lower 80s °F (27-29°C).

GENERAL WEATHER. The trade wind inversion's disappearance is the major transition weather feature. The weakening inversion layer eliminates the source of dry, adiabatic northeasterlies. The sea breeze circulation intensifies and generates diurnal convection. In late spring, frontal passages occasionally descend into the region. Figure 3-37 illustrates the clouds and weather that often accompany weak polar surges.

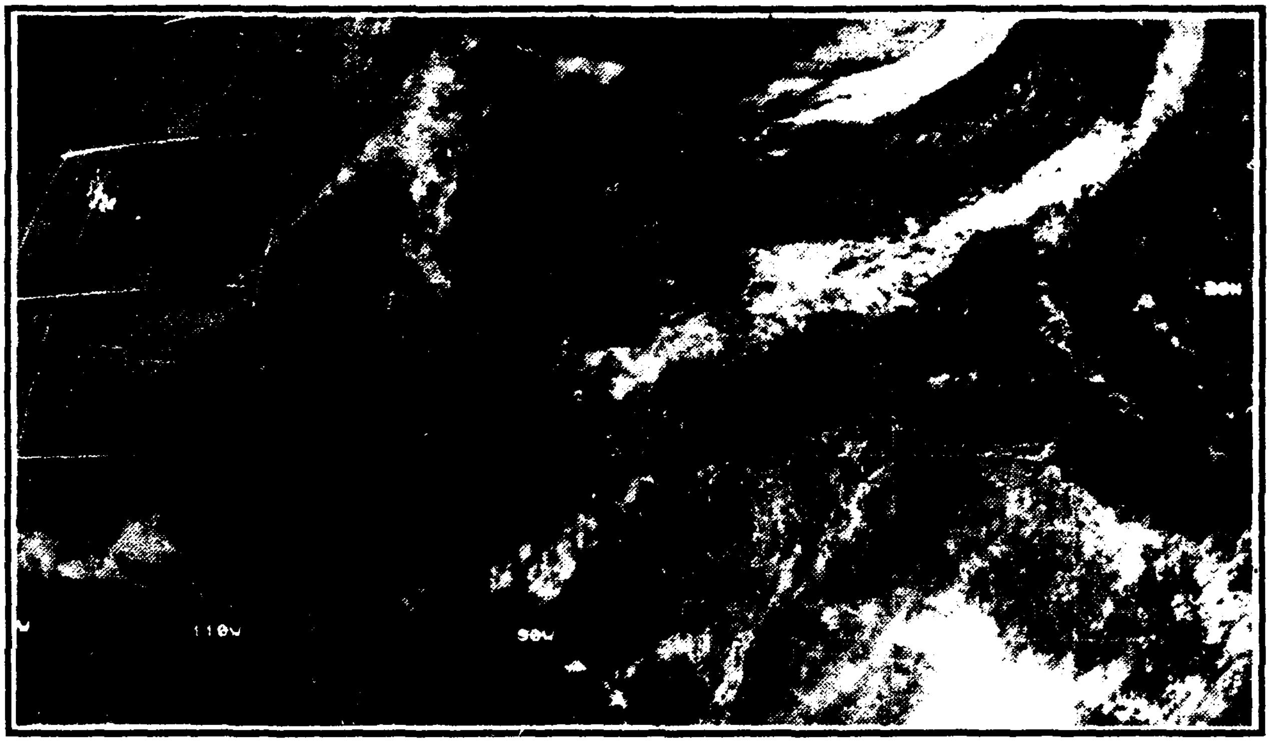


Figure 3-37. A Weak Frontal Passage Enters the Lakes Region. These fronts rarely have significant weather along the frontal boundary. Typically, the sheared front creates instability aloft, which enhances the pre-established synoptic pattern. In this 12 April 1976 case, the Monsoon Trough over southern Central America is well-developed; cloudiness develops along the northern extension of the Monsoon Trough.

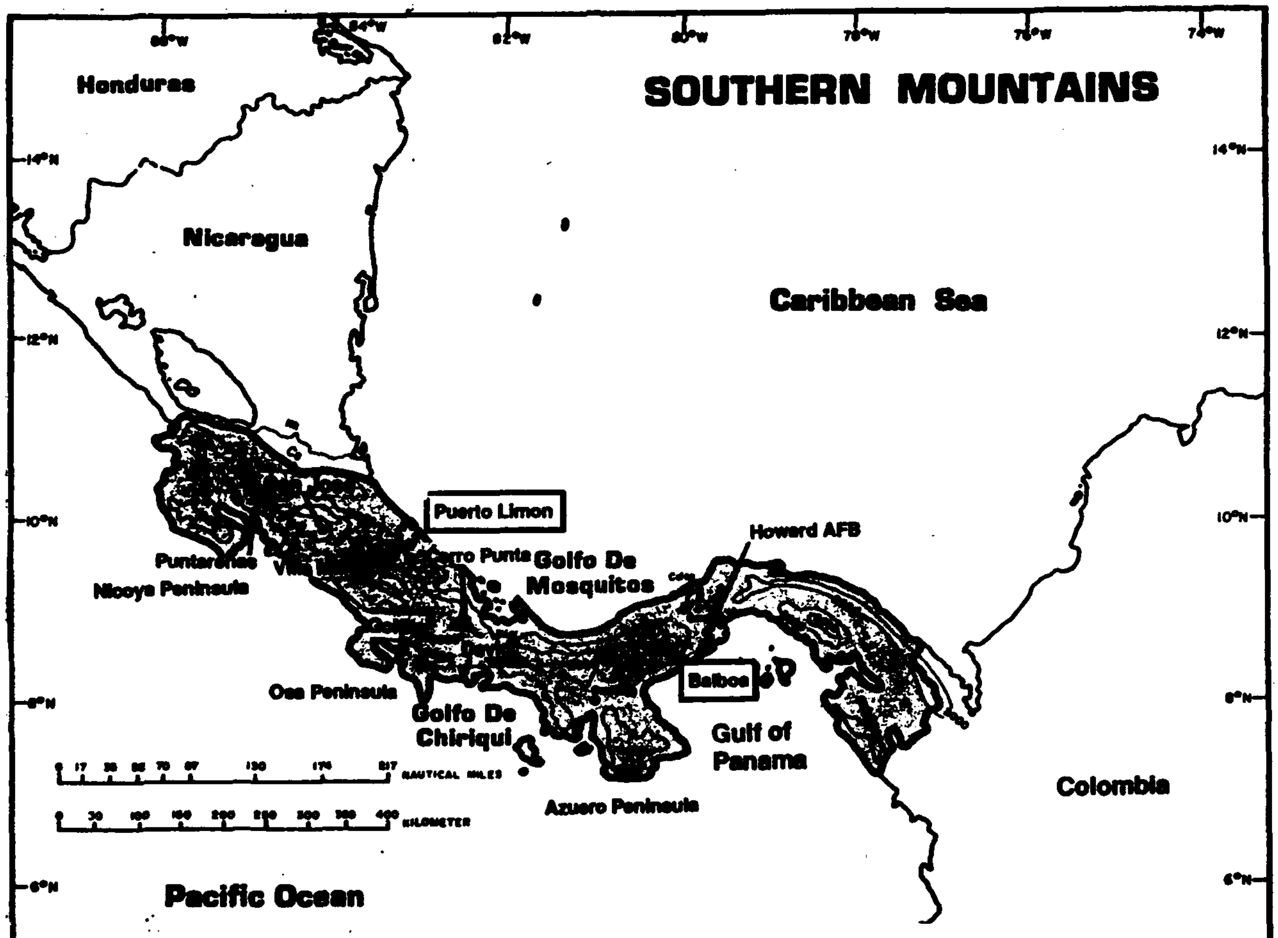
SKY COVER. During episodes of Monsoon Trough convergence, sky cover will be 4 to 6/8ths cumulus with tops to 20,000 feet (6.2 km) and bases at 2,000-3,000 feet (610-915 meters). Diurnal convection (in the absence of additional sources of instability) prohibits cumulus from extending beyond 15,000 feet (4.8 km) due to the tradewind inversion. Mornings along the lakes can see 6 to 7/8ths coverage of light stratiform cloud due to radiation cooling over land and lakeshore breezes that sweep moisture ashore. These layers are at 4,000-6,000 feet (1,220-1,830 meters), with bases as low as 1,000 feet (330 meters). They burn off quickly, however, when the sun begins to generate the land/sea breeze mechanism.

WINDS. Normal northeasterly flow averages 5-8 knots, but onshore Monsoon Trough flow can produce gusts to 15 knots. Maximum speeds are reached during mid-afternoon in response to sea breeze reinforcement of onshore flow. The decrease in descending mountain airflow from the east allows the sea breeze to penetrate deep into the interior.

PRECIPITATION. All locations in the Lakes region get more than 5 inches (127 mm) of rain during May, a ten-fold increase over April.

TEMPERATURE. Late dry season conditions see the greatest insolation. Clear skies allow an average high in Managua of 93°F (34°C). Lows remain balmy, with 74°F (23°C) normal. Along the lakes, daytime temperatures can be as much as 3°C cooler during the day and 2°C warmer at night because of the moderating effects of these large water bodies.

3.6 THE SOUTHERN MOUNTAINS



PUERTO LIMON

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	90	78	64	13.5	83	71	0	6.5
FEB	92	78	61	8.6	83	71	0	3.8
MAR	92	80	64	8.3	85	72	0	7.1
APR	95	81	65	9.2	85	73	2	6.3
MAY	94	82	67	13.5	86	75	6	4.7
JUN	94	81	68	11.1	85	75	11	4.8
JUL	90	80	67	16	84	74	10	6.4
AUG	90	81	70	12.1	85	74	11	6.2
SEP	94	82	68	5.1	86	74	10	2.7
OCT	91	81	68	9	85	74	8	3.8
NOV	92	80	67	15.5	84	73	4	10.3
DEC	90	78	68	18	83	72	1	8.2

BALBOA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	92	80	66	1.7	88	73	1.2	1.5
FEB	94	80	64	.7	80	74	.6	1.9
MAR	98	82	66	.5	91	74	.1	1.2
APR	95	82	68	2.5	92	75	3.8	2.9
MAY	95	81	70	8.5	88	76	18	7.2
JUN	93	80	71	8.2	88	75	14.4	4.2
JUL	93	80	70	7.7	88	75	15.6	5.4
AUG	93	80	68	8	88	75	17.5	4.4
SEP	92	80	70	7.6	87	74	16.3	5.1
OCT	92	79	69	11.1	87	74	18.5	4.9
NOV	92	79	68	10.3	88	74	11	4.6
DEC	92	80	68	5.6	88	74	4	2.6

Figure 3-38. The Southern Mountains. This region is bounded on the north by a line drawn at the 500-foot (150-meter) contour and running from La Cruz (on the southern shore of Lake Nicaragua) to Puerto Limon on the Caribbean coast. From this line south, the region encompasses all the rest of Costa Rica and Panama. Only narrow coastal plains interrupt the mountainous terrain that runs the full length of the region. Several peaks rise to well over 10,000 feet (3,050 meters). Insets provide climatic summaries for Puerto Limon, Costa Rica, and Balboa, Panama.

SOUTHERN MOUNTAINS GEOGRAPHY

A high ridge of mountains extends through the central sections of Costa Rica and western Panama. These extensive mountain systems include numerous inactive volcanos, most of which are in central Costa Rica and near the Costa Rica-Panama border. The tops of these cones run between 10,000 and 12,000 feet (3,050 to 3,660 meters). The northern and southern extremes of this mountainous region have maximum elevations of 5,000 to 7,000 feet (1,525 to 2,135 meters). The mountains slope quickly into the coastal regions, leaving only narrow plains in most areas. Exceptions are found mainly where bays, lagoons, and gulf areas have been cut into both coastlines.

Several large peninsulas jut into the Pacific; three of these are of particular interest:

The Nicoya Peninsula, in extreme northwestern Costa Rica, is covered with rolling hills that have tops near 3,000 feet (915 meters). The Gulf of Nicoya, along the southern edge of the peninsula, separates it from the mainland.

The Osa Peninsula is in southwestern Costa Rica. Smaller than the Nicoya, it also has a few hills, but most of it is covered with mangrove swamps and marshland. It is the drainage basin for numerous rivers flowing from the mountains on the mainland to the sea.

The Azuero Peninsula, in western Panama, covers 100 sq mi (256 sq km) and is relatively flat with only isolated hills. It is covered with small rivers and expanses of marshland. The peninsula divides two of the largest gulfs in Central America: the Gulf of Chiriqui and the Gulf of Panama.

The Caribbean coastal side of the Southern Mountains region is relatively unbroken, interrupted briefly in western Panama by the Chiriqui Lagoon and Almiranti Bay. There is almost no coastal plain except near the Isthmus of Panama.

There are several noteworthy valleys in the Southern Mountains. The San Jose Valley in central Costa Rica runs northwest to southeast. Although it is well above sea level (3,000 to 4,000 feet--915 to 1,220 meters) it is surrounded by ridges pushing to well over 10,000 feet (3,050 meters). Another valley, near the border of Costa Rica and Panama, runs parallel to the ridge line and dips to 540 feet (165 meters) at its lowest point. This southern valley is an ideal collection point for numerous mountain streams that run into the Terraba River, which then flows into the Pacific near the Osa Peninsula.

Tropical/subtropical evergreen seasonal broadleaved forests dominate the region except in marshy peninsula areas where dense ferns and small mangroves prevail.

GENERAL WEATHER. Complex topography and extremely unstable conditions resulting from low-level moisture convergence (Pacific/Atlantic air masses) and complex topography contribute to extremely wet conditions here during the summer wet season. The Monsoon Trough and moist, northeasterly tradewinds consistently produce unstable conditions, thundershowers, and heavy isolated areas of rain. Persistent low-level tradewind convergence enhances the diurnal convective cycle. Typically, clouds develop immediately after the 0900 LST onset of the sea breeze. Extensive volcanic ridges provide orographic uplift. Stationary convergence lines (oriented west to east) establish along these ridges and bring heavy rainfall to the interior.

SKY COVER. On the Caribbean coasts of Costa Rica and Panama, sea breezes reinforce the northeast trades. Caribbean moisture pushes inland along windward slopes and lifts orographically. Convergence lines develop along the windward slopes and spread out into the coastal plains. Typically, tradewind cumulus forms by 1000 LST with bases of 3,000-4,000 feet (915-1,220 meters), building to 20,000 feet (6,100 meters) by 1400 LST. Figure 3-39 compares ceiling frequencies for Puerto Limon, Costa Rica, Howard AFB, Panama, and San Jose, Costa Rica. It clearly shows the difference between windward (Puerto Limon) and leeward (Howard and San Jose) situations.

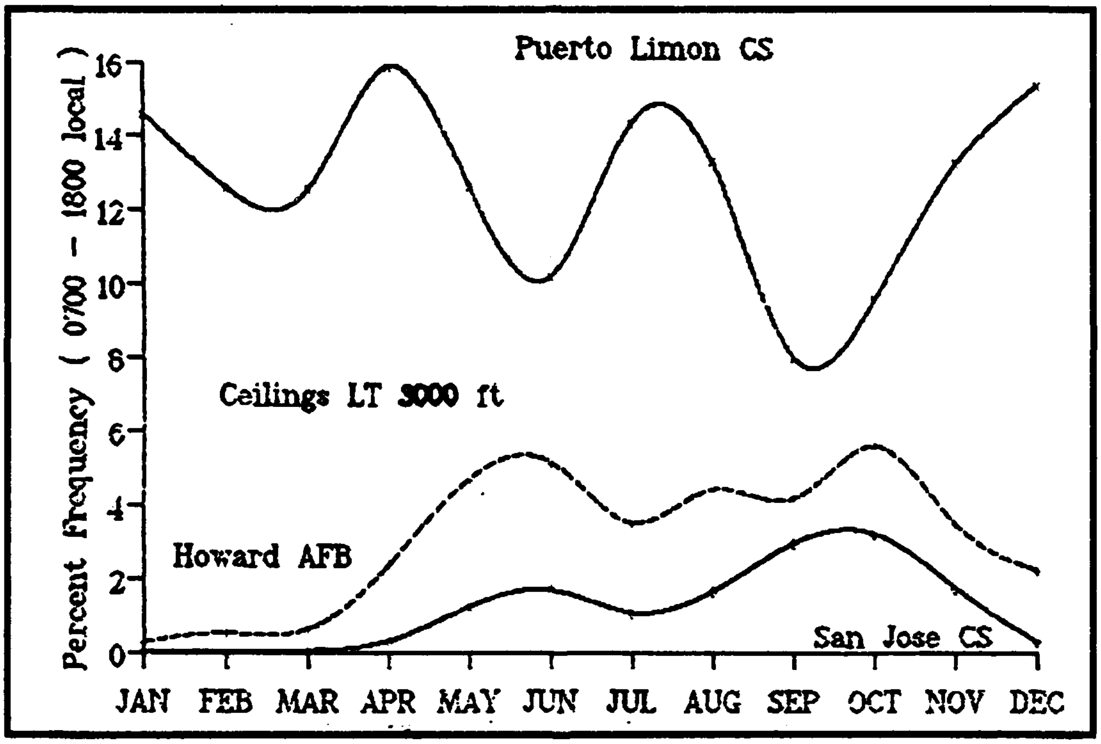


Figure 3-39. Percent Frequency of Ceiling: Three Southern Mountains Locations. Percent occurrence frequency curves show that Howard and San Jose peak (although still less than 6 percent) late in the wet season as the Monsoon Trough dominates the synoptic scale weather pattern. Since southwesterlies now prevail, San Jose's leeside orientation to northeasterlies is altered. In the case of Puerto Limon, terrain is more of a factor; the tradewind inversion confines moisture to Caribbean slopes early in the wet season. Puerto Limon's coastal configuration also enhances onshore flow. Late in the wet season, southwesterlies produce a rain shadow effect, and low ceilings are less frequent.

WINDS. Flow is sustained northeasterly (5-9 knots); however, synoptic-scale southwesterlies prevail from July to October in southern Costa Rica because of the Monsoon Trough. These winds are concentrated here because of the high terrain (oriented WNW to SSE) that diffuses their effect further east into Panama. The complex terrain and coastal configurations in this region, along with complex sea breeze-synoptic flow interactions, produce local surface winds that can vary from prevailing flow by 45 to 90 degrees. Localized

zones of convergent/divergent wind fields make large-scale wind forecasting difficult. The Canal Zone, as well as the northwest interior and southern coasts of Panama, is particularly complex with regard to local wind patterns. Pacific flow (southerly) only reaches 5-15 NM inland, and is a function of sea breeze circulation along southern coastlines.

THUNDERSTORMS. The diurnal convection cycle produces numerous large-scale thunderstorm cells, some reaching to 40,000 feet (12.2 km). Low-level convergence between sea breeze circulations fuels the activity. A secondary source of thunderstorm activity is concentrated in the mountainous interior. Orographic uplift produces 70-90 thunderstorms a year in the mountains, versus 40-60 a year over the plains.

HURRICANES rarely make landfall in the Southern Mountains region. The only recorded occurrence was in late November 1969, when Hurricane Martha, with a 980 mb central pressure and maximum winds of 80 knots, struck the northern coast of Panama. Five deaths were reported in Costa Rica due to flooding and landslides; damage estimates were upwards of $30 million. Martha originated as a cutoff low generated by the Monsoon Trough. No rainfall amounts were available.

PRECIPITATION. Rainfall amounts throughout the Southern Mountains region are generally more than 6 inches (152 mm) a month from May through October. The southwesterlies, which prevail from July through October, increase southern Costa Rican rainfall but have little effect elsewhere in the region, which is sheltered from southwesterly flow by terrain.

TEMPERATURES. Along northern coasts, highs are consistently in the 83-87°F (28-31°C) range. Overnight lows, moderated by the ocean, range from 69-72 °F (21-22°C). It is considerably cooler in the higher elevations of the windward ranges because of adiabatic processes. For example, Villa Mills, Costa Rica (at 10,157 feet/3,097 meters) averages highs of 60-64°F (16-17°C), and lows of 41-42°F (5°C). In contrast, San Jose (at 3,845 feet/1,172 meters) averages 78-80°F (25-27°C) during the day and 60-61°F (16°C) at night. In Panama, Cerro Punta (at 6,110 feet/1,863 meters) averages highs of 68-69°F (20°C) and 49-52°F (9-11°C) for lows. On the coast, Howard AFB averages 86-89°F (30-32°C) during the day and about 75°F (24°C) at night.

GENERAL WEATHER. Subsidence aloft is the primary feature of wet-to-dry transition weather. Developing anticyclonic circulation (northerly at 500 millibars) and reinforcing surface conditions (cooler land and sea surface temperatures) stabilize the atmosphere. The trade wind inversion, which averages 6,600-8,200 feet (2,100-2,500 meters), dampens vertical trade wind cumulus development. Only a temporary synoptic-scale northward surge in the Monsoon Trough destroys the developing subsidence during this period. Figure 3-40 shows a Monsoon Trough disturbance migrating northwestward toward the Southern Mountains.

Figure 3-40. Monsoon Trough Convection. In this 15 November 1975 photo, cloud clusters are the result of orographic uplift of equatorial moisture along the Andean Chain in Colombia. These clusters move over warm waters, intensify, and travel northward. The northeast trades, however, steer the clusters westward. Clouds (mostly cirrus and stratocumulus) reach the southern coasts of the region, occasionally accompanied by light showers.

SKY COVER. Thunderstorms associated with the Monsoon Trough and land/sea breeze persist in certain parts of the Southern Mountains as late season surges push the Trough briefly northward. Cloud cover averages from 5 to 6/8ths during the day. Bases are 3,000-4,000 feet (915-1,220 meters) along windward slopes, on mountain peaks and ridge lines, and on the interior coastal plains. Tops average 12,000 feet (3.8 km), but may reach 17,000 feet (5.3 km). Bases of the leeward cumulus average 4,000-6,000 feet (1,220-1,830 meters. The introduction of the trade wind inversion decreases mean cloud cover on the lee (Pacific) side of major barriers during the transition due to adiabatic processes. Late in the transition, undisturbed conditions produce thin altostratus with mixed trade wind cumulus. By midday, bases are 3,000-5,000 feet (915-1,245 meters). Tops reach 9,000 feet (2,745 meters) in the lowlands. Stratus covers ridge crests above 6,000 feet

(1,830 meters) in the morning, later changing to 1 to 3/8ths isolated trade wind cumulus with bases at 2,000 to 3,000 feet (645-915 meters). Evenings typically revert to broken stratus in response to a lack of surface-induced convection.

WINDS. Prevailing direction is from the northeast. Speeds are light and variable (5-8 knots), but typically increase with height (10-15 knots at 3,000 feet/915 meters). Local topography can isolate certain areas and create unique circulation patterns. An example is at Golfito, Costa Rica, where mountain winds from the northeast combine with local sea breezes to produce blustery conditions and moderate cumuliform development.

PRECIPITATION. December thunderstorm days at all locations decrease to one-half the wet season totals. The northeasterly trades produce adiabatic leeside drying. This drying phenomenon affects the southern Costa Rican coastline except at Golfito, where more than 1 inch (25 mm) of rain falls in December. Local terrain and wind circulations are responsible for all such unique and isolated conditions. Southern Panama's dry transition conditions are similar to those in southern Costa Rica. A strong inversion limits Caribbean moisture inland along the northern coast, confining cloud cover and instability showers to the immediate coasts--most moisture is lost quickly over land.

TEMPERATURE. Average highs range between 82 and 91°F (28-33°C) in November and December. The number of days with 90°F (32°C) or better varies from 5 to 12 a month over the entire region. Lows are generally between 62 and 69°F (17-20°C).

GENERAL WEATHER. The trade wind inversion and the Andean Mountain chain are the most influential factors in determining dry season weather; increased subsidence generated along and above the inversion significantly restricts tradewind cumulus and thunderstorm activity. The Andes Mountains, however, deflect equatorial southwesterlies and force orographic lifting of warm Pacific moisture. Uplifted air intensifies into convective cloud clusters along the Monsoon Trough from 3 to 7 degrees North during winter and early spring.

SKY COVER. The Caribbean coasts of Costa Rica and western Panama (as well as their adjacent windward interiors) see 2 to 3/8ths cloud cover by 1000 LST. During late afternoon, windward slopes see maximum cloudiness as air is lifted orographically. Sky cover peaks at 5 to 6/8ths during the dry season. Bases are generally between 2,000 and 3,000 feet (610-915 meters); tops rarely reach above the base of the trade wind inversion, which is now at 6,000-8,000 feet (1,830-2,440 meters). On the Pacific side of the mountains, the percentage of possible sunshine reaches 90 percent in March. From Puntarenas northwestward into Nicaragua, the mountains create a lee side rain shadow where skies are nearly cloudless all day. Cloud cover averages only 1/8th and rarely exceeds 3/8ths. Bases rarely form above 4,000 feet (1,220 meters), even during the afternoon. Cloudiness along the Isthmus of Panama depends on the location of the convergence line resulting from the northeasterly trade flow and airflow deflected by the Andes. By midday, sky cover averages 4 to 6/8ths as clouds drift near shore. Tops rarely exceed 12,000 feet (3.7 km), but cells may produce light to moderate rainfall that is localized, short-lived, and typically generated along the edges of cumulus canopies.

WINDS. Light to moderate turbulence is more frequent in the dry season because of the strong trade wind inversion in the lower atmosphere. Moderate clear air turbulence and mountain lee waves can develop with descending northeasterly flow along the lee (Pacific side) of the extensive mountain ranges of Costa Rica. Large amplitude waves, particularly during March, are formed by the adiabatic compression of northeasterly flow passing over the complex terrain. Downslope breezes can reach 20-30 knots at the surface with isolated valley circulations shifting wind directions 90 degrees to the prevailing flow.

PRECIPITATION. The Southern Mountains are driest in March. Costa Rica's extensive mountain ranges separate Costa Rica and western Panama into two separate and distinct dry season precipitation zones. The Pacific side has a 4-5 month dry season, but on the Caribbean side it lasts only 3 months. The Pacific side averages less than 1/2 inch of rainfall (13 mm) a month during its dry season, but the Caribbean side is ten times wetter. Essentially, the Caribbean side's "dry" season occurs only when the trade wind inversion inhibits thunderstorm activity and decreases the amount and frequency of heavy rainfall. High terrain on the Caribbean side rises above the trade wind inversion and acts as a wall separating moist windward flow from dry leeward flow. The northeasterlies sweep moist Caribbean air inland to the windward slopes. This moisture remains below the inversion layer and condenses to result in drier flow along the ridge crests. The same northeasterlies compress over the ridges and descend leeward slopes adiabatically. During the abbreviated "dry" season, orographic convection persists in the moist Caribbean air mass on the windward side of mountain slopes and below the trade wind inversion. Since the inversion limits vertical cloud development to only about 8,000 feet (2,440 meters), light to moderate showers--rather than thundershowers--dominate the windward slopes.

TEMPERATURE. Generally, mean daily temperatures are warmer in the winter dry season than in the summer wet season. Polar outbreaks, however, can bring below freezing temperatures to the higher elevations. In Costa Rica, average highs below 3,000 feet (915 meters) range from 82 to 87°F (28-30°C) on the Caribbean side and 89-95°F (32-35°C) on the Pacific side. Puntarena, Costa Rica, is the warmest spot in the region, averaging 95°F (35°C) daily. In Panama, the average temperature remains constant at 86-88°F (29-30°C) throughout the dry season.

GENERAL WEATHER. Intensifying sea breezes and low-level convergence into the northward migrating Monsoon Trough are the dominant dry-to-wet transition features. Low-level convergent sea breezes accelerate the diurnal convection cycle under clear springtime skies. Surface heating, in turn, heats the atmosphere. The trade wind inversion weakens and allows vertical development of tradewind cumulus. Thunderstorm activity increases dramatically. The Monsoon Trough increases instability aloft and pumps equatorial moisture to the 700-millibar level, sustaining diurnal convection.

SKY COVER. Mountain slopes and ridges may be totally enveloped in cloud from 1000 to 1600 LST. Tops can reach 20,000 feet (6.2 km). Bases generally form at 2,000-3,000 feet (610-915 meters) with visibilities between 3 and 6 miles. Along coastlines, cloud cover becomes 2 to 3/8ths by midday; tops average 10,000 feet (3,280 meters), bases 2,000 feet (610 meters). Visibilities are rarely less than 6 miles.

WINDS. With the increase in sea breeze circulation resulting from increased insolation, northeasterly winds along Atlantic coasts become stronger during morning hours. Generally light and variable until 0900 LST, speeds increase to 10 knots by midday when the sea breeze mechanism is in full gear. By late afternoon, downdrafts from heavy cumulus can produce gusts up to 25 knots. Topography in this mountainous region accelerates and obstructs winds, creating turbulent eddies that are difficult to forecast. On the Pacific coasts, flow is also northeasterly. When the Monsoon Trough is favorably positioned, however, southeasterly flow moves onshore temporarily at 6-10 knots; this flow is only temporary because of the Trough's diurnal oscillation. Onshore flow, coupled with downslope currents off the mountains, can create convergence lines inland. Winds near these lines average 10-20 knots and vary in direction.

THUNDERSTORMS. Increases in the frequency of Monsoon Trough surges produce strong convergence line thunderstorms along the interior mountains. Small hail and strong winds (25-40 knots) may occur in isolated towers that reach above 30,000 feet (9.5 km). These storm cells can intensify and eventually spread downwind onto the plains, creating heavy downpours and localized flash flooding.

PRECIPITATION. In April, most locations get between 1 and 3 inches (25-76 mm) of rain, but by May, monthly rainfall everywhere has increased to at least 8 inches. (203 mm) Most rainfall is either from intense thunderstorms spawned by the Monsoon Trough or from the effects of orographic uplift. On the northwest Atlantic coast, May rainfall averages over 13 inches (330 mm), due primarily to the reinforced sea breeze.

TEMPERATURE. Increased sunshine early in the period maximizes temperatures by April. The onset of the wet season produces slightly lower mean daily highs because of the increase in cloudiness during daylight hours. In the mountains, average spring temperatures are significantly cooler, the result of elevation and large increases in cloud cover. The mean range for temperatures at lower elevations is 87-93°F (31-34°C) for highs and 70-74°F (21-23°C) for lows. At the higher elevations, highs remain mild, averaging 74-78°F (23-25°C) during the day and 61-67°F (16-20°C) at night.

Chapter 4

THE WEST INDIES

This chapter describes the situation and relief, major climatic controls, geography, and general weather of the West Indies, a geographical grouping that comprises a large number of islands stretching from northwest to southeast across the entire Caribbean Basin. For this study, these islands have been sorted into four climatologically similar groups as shown in Figure 4-1, overleaf. This chapter will address each of these four regions in considerable detail.

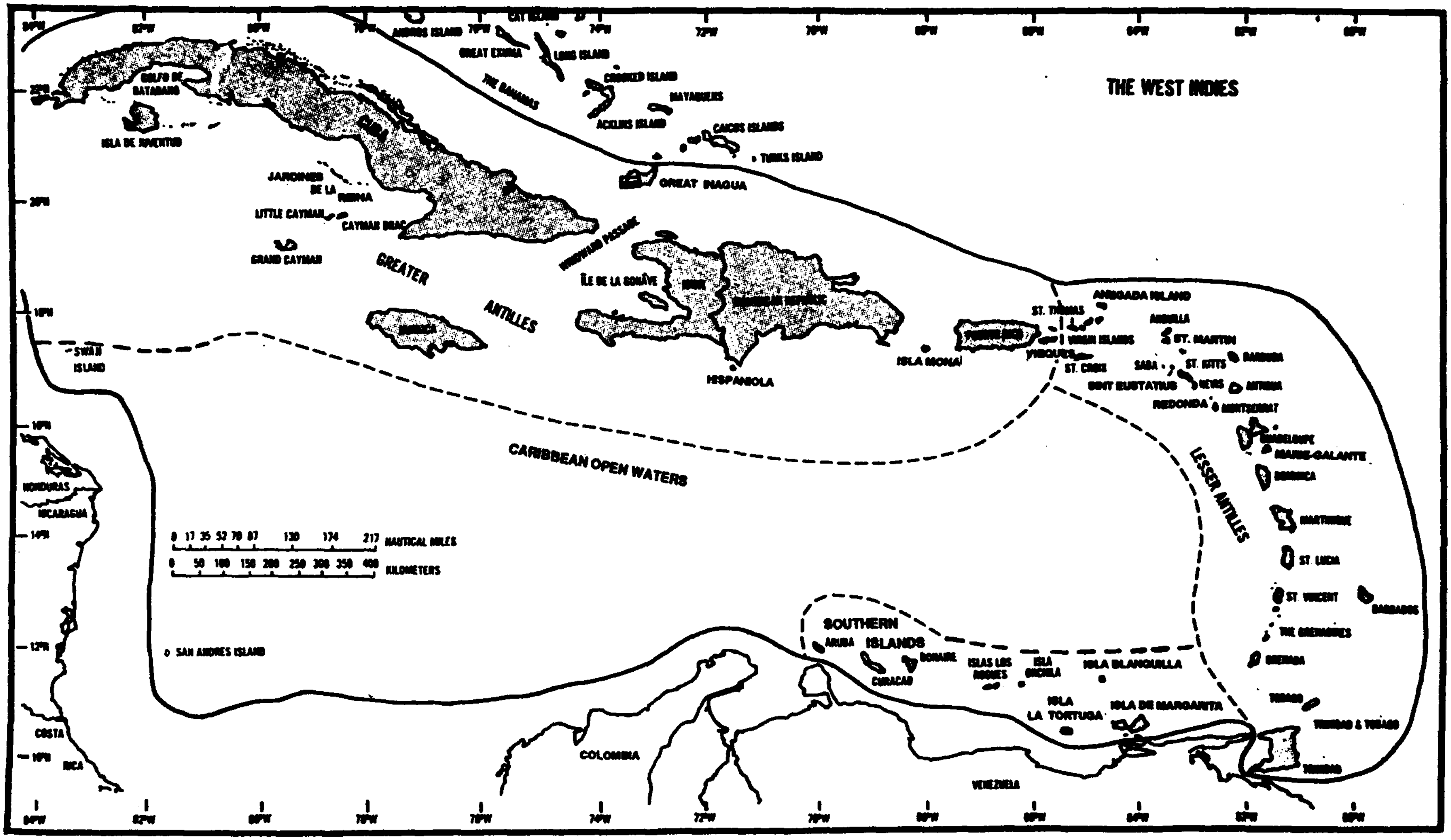


Figure 4-1. The West Indies. This group of islands comprises the Greater Antilles, the Lesser Antilles, the Southern Islands (or Netherland Antilles), and a "Caribbean Open Waters" region.

THE WEST INDIES

SITUATION AND RELIEF. The West Indies divide the Caribbean Sea from the Atlantic Ocean. For this study, the islands that make up the West Indies are divided into four groups; as shown in Figure 4-1, these are the Greater Antilles, the Lesser Antilles, the Southern Islands (or Netherlands Antilles), and the Caribbean open waters.

The West Indies cover a vast extent of water. Trinidad lies about 1,700 miles (3,145 km) from Belize and about 1,650 miles (3,052 km) from Miami. The southern coast of Trinidad is almost exactly 10 degrees north of the equator, and the northern coast of Cuba (at Havana) is at about 23 degrees north. All the islands are surrounded by the warm waters of the Caribbean Sea which, thanks to the North and South Equatorial Currents of the Atlantic, seldom falls to less than 80°F (26°C) at the surface. As expected, the entire island chain enjoys what one might call "tourist weather."

Mountainous features and warm surrounding waters are the two major geographical factors that influence West Indian weather. The great mountain system that stretches from Alaska to the tip of South America was formed by tectonic folding millions of years ago. Although relatively minor, a branch of that system extends through the West Indies. Many of the eastern islands are the above-water remains of partially submerged mountains, many with volcanic features and some still active. Most of the West Indian islands are formed of folded sediments, but the island of Dominica, among others, is entirely volcanic in origin.

The tallest peak (10,128 feet--3,053 meters) in the West Indies is in the center of the Dominican Republic. Another reaches 8,773 feet (2,674 meters) near Port-Au-Prince, Haiti. Others in the Greater Antilles reach to 7,700 feet (2,347 meters) on the southwestern tip of Haiti; to 7,402 feet (2,256 meters) near Kingston, Jamaica; and to 6,542 feet (1,994 meters) on the south coast of Cuba. In contrast, the highest peak in the entire Lesser Antilles reaches only 4,813 feet (1,467 meters) at Guadalupe. Earthquake activity is common, much of it centered in the Puerto Rico trench which, at nearly 30,000 feet (9,144 meters) is the greatest known depth in the Atlantic.

Nearly all West Indian towns of any consequence are seaports. Since most of the airfields (and, as a result, most of the observing sites) in the islands are at or near sea level, it should be noted that much (but not all) of the climatic data for the West Indies is typical of that exposure and elevation.

MAJOR CLIMATIC CONTROLS. The West Indies are dominated by two major features:

The North Atlantic (or Azores) High Pressure Cell is part of the belt of high pressure (or descending Hadley circulation) encircling the earth at about 30 degrees north. The proximity of this high's center to the West Indies increases atmospheric stability during the northern hemisphere winter and results in decreased precipitation and a "dry season." The cell's northward migration from 30 to 35 degrees north during northern hemisphere summer results in decreased atmospheric stability, increased convection, and a "wet season." Seasons (separated by short transition periods) throughout the West Indies are generally classified as follows:

·*Dry-Wet Transition* (mid-April to mid-May)

·*Wet Season* (May to November)

·*Wet-Dry Transition* (mid-November to mid-December)

·*Dry Season* (December to April)

Wet and dry seasons are discussed in detail in subsequent sections devoted to each region. Although a detailed discussion of "seasons" is not included in the section on the "Caribbean Waters" region, conditions on several small islands there are discussed and can be considered representative of conditions over open water.

Local Terrain. The terrain itself is the second major climatic factor influencing local climate. Mountainous areas, such as those found on the four main islands in the Greater Antilles group, for example, often modify the climate on windward and upper leeward slopes due to orographic uplift of moist easterly trade winds. Because of this effect, some places don't have the clearly defined wet and dry seasons common to most of the Indies.

4.1 THE GREATER ANTILLES

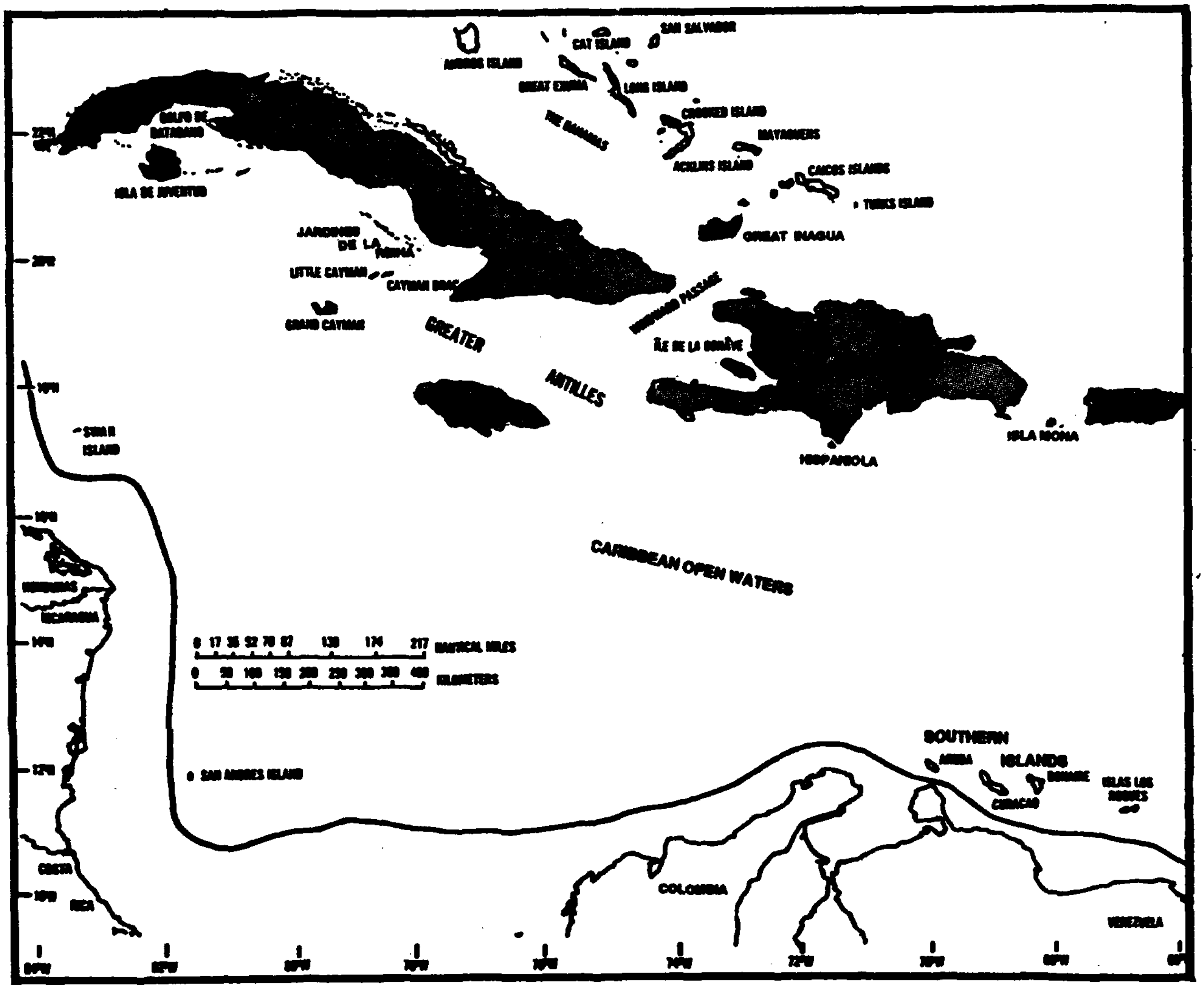


Figure 4-2. The Greater Antilles. This region comprises four major islands and some lesser islands nearby. The major islands are: Cuba, Jamaica, Hispaniola (Haiti and The Dominican Republic), and Puerto Rico. Like the rest of the Indies, the Greater Antilles have a dry season, a wet season, and two brief transition periods.

4.1.1 CUBA

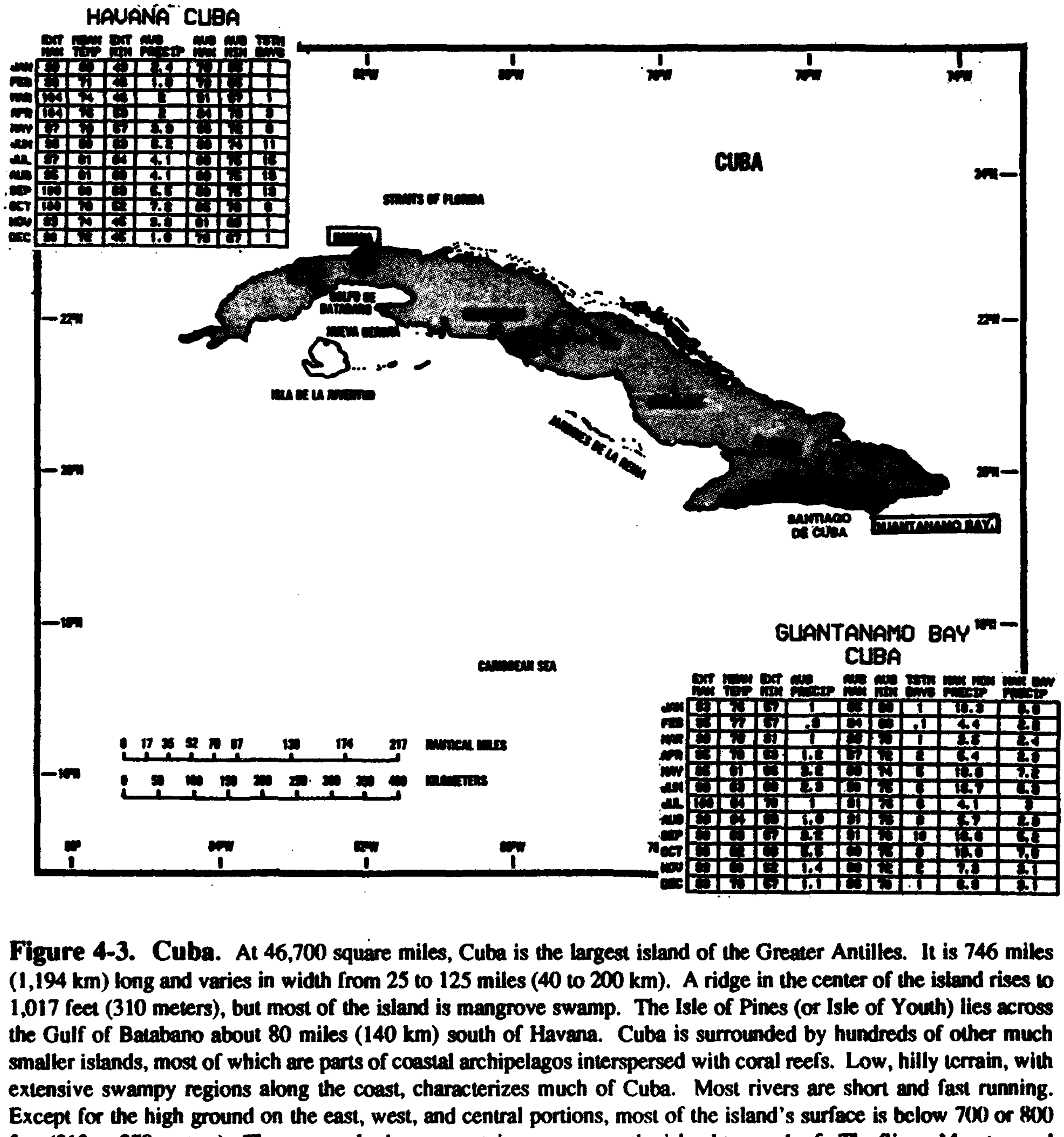


Figure 4-3. Cuba. At 46,700 square miles, Cuba is the largest island of the Greater Antilles. It is 746 miles (1,194 km) long and varies in width from 25 to 125 miles (40 to 200 km). A ridge in the center of the island rises to 1,017 feet (310 meters), but most of the island is mangrove swamp. The Isle of Pines (or Isle of Youth) lies across the Gulf of Batabano about 80 miles (140 km) south of Havana. Cuba is surrounded by hundreds of other much smaller islands, most of which are parts of coastal archipelagos interspersed with coral reefs. Low, hilly terrain, with extensive swampy regions along the coast, characterizes much of Cuba. Most rivers are short and fast running. Except for the high ground on the east, west, and central portions, most of the island's surface is below 700 or 800 feet (213 or 278 meters). There are only three mountainous areas on the island to speak of. The Sierra Maestra and Sierra del Cristal mountain ranges join to run from east to west along the southern coast of eastern Cuba near Guantanamo. Elevations here drop steeply to the southern shore, broken only by Guantanamo Bay. Ridges are generally above 3,000 feet (914 meters), but some peaks are above 5,000 feet (1,524 meters). The highest of these is Pico Turquino in the Sierra Maestra at 6,542 feet (1,994 meters). Another less impressive mountainous feature runs along the south-central coast near Cienfuegos; the highest point of its largest feature (Loma San Juan) is 3,773 feet (1,150 meters). The third range (Sierra Del Rosario) is on the western part of the island; this ridge runs southwest to northeast for about 100 miles and reaches 2,270 feet (692 meters) at its highest point.

GENERAL WEATHER. Large-scale flow changes from the northeasterly flow of the dry season to become more easterly. The trade wind inversion begins to weaken and rise as the Azores High migrates north; upper-level subsidence becomes less pronounced. As subsidence lessens, the unstable lower layers become deeper and allow convective precipitation to become more widespread. Polar outbreaks are still possible early in the transition, but their strength and frequency are greatly reduced. Local effects such as land/sea breezes and mountain/valley winds become more significant.

SKY COVER. Increasing low-level instability is reflected by the higher percentage of ceilings/visibilities below 3,000/3, especially in the afternoon; percent frequencies increase from just over 30% in March to nearly 50% by May. Cumulus tops now are often above 10,000 feet (3.1 km).

WINDS. Low-level winds remain easterly below 10,000 feet (3.1 km); at higher levels, mean winds are still northwesterly.

THUNDERSTORMS. The mean number of days with thunderstorms increases from an average of one in March to more than five a month by May. Thunderstorms can occur with the isolated polar outbreak early in the season, especially on the northwestern edge of the island.

PRECIPITATION. Increasing instability in the lower levels is reflected in the increase in precipitation; by May, average monthly rainfall is nearly 4 inches (102 mm). Totals on the eastern edges of the island are more than an inch less, however, thanks to the protection afforded by the nearby hills.

TEMPERATURES. There is little change in mean temperature from the dry season. Average highs run from the low to mid 80s°F (28-30°C), and mean lows are in the low 70s°F (22°C).

GENERAL WEATHER. By September, the persistent trade winds assume a more east-southeasterly component and bring warmer air over the island. The depth of the low-level trade winds increases. The northward migration of the Azores High (to about 35° N, 40° W) results in less subsidence aloft and more instability. The trade wind inversion becomes weaker and rises to over 9,000 feet (2.7 km), permitting convection to increase. During July, however, the western lobe of the Azores High moves across Cuba to temporarily raise pressure, increase subsidence and stability aloft, and suppress convection. Many parts of Cuba experience a "mini dry season" at this time.

SKY COVER. Cloudiness is at its maximum, averaging 5 to 7 tenths coverage. Ceilings/visibilities are below 3,000/3 from 10 to 30% of the time at most locations, but may be less than 1,000/2 up to 10% of the time. There is more cloudiness in the higher elevations. Afternoons are cloudiest as convective clouds build. Figures 4-4a and 4-4b clearly indicate the greater wet season diurnal variation in cloud cover. Since Guantanamo Bay is protected on two sides by mountains, the percent frequency and diurnal variation in cloud cover here are much less than at other locations on the island, even in summer.

Visibility is typically very good, averaging better than 6 miles 90% of the time. Sudden showers may restrict ceiling and visibility to near zero for short periods. Cumulus cloud bases are usually 2,000 to 4,000 feet (610 to 1,220 meters) with tops exceeding 10,000 feet (3.1 km). Some alto...tus and cirrus may be present. Passage of easterly waves, tropical storms, or hurricanes results in well-developed altostratus and nimbostratus with embedded cumulonimbus. Reduced visibility in fog is infrequent and usually restricted to interior valley locations. Light haze is often present, but it rarely restricts visibility to less than 5 miles. The freezing level is about 15,000 feet (4.6 km); icing may be found above that, primarily in towering cumulus and cumulonimbus. Turbulence is expected in or near convective clouds.

WINDS. The easterly trades dominate, but the passage of easterly waves, tropical storms, or hurricanes tends to disrupt the normal easterly/northeasterly flow. Mean speeds are still 5-10 knots, but local terrain features often modify the prevailing wind. Because the easterly trade winds are blocked by mountains to the north, locations on the southern coast of Cuba are more prone to land/sea breeze effects. Early morning winds are northerly or northeasterly as cool air drains down out of the

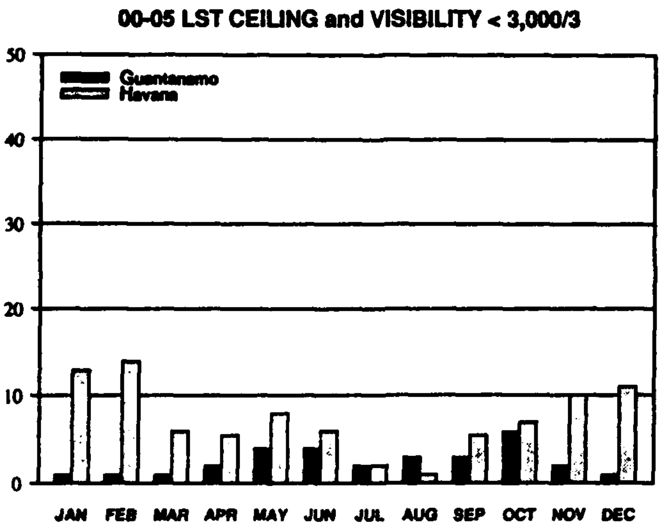


Figure 4-4a. Percent Frequency Ceiling/visibility <3,000/3, 00-05 LST, Havana vs. Guantanamo Bay.

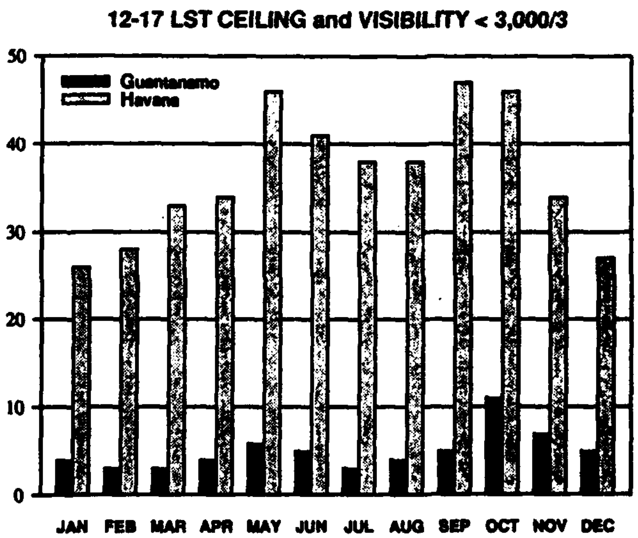


Figure 4-4b. Percent Frequency Ceiling/visibility <3,000/3, 12-17 LST, Havana vs. Guantanamo Bay.

mountains. A southerly sea breeze often sets up in the afternoon. In September, winds are easterly up to 25,000 feet (7.6 km), turning to become north-northwesterly from 32,000 to 48,000 feet (9.8 to 14.634 km), and returning to easterly above 48,000 feet.

TROPICAL DISTURBANCES. Tropical storm activity increases through the wet season, peaking in August, September, and October. Activity is least at the beginning and end of the wet season; frequency is only 2% in May and 7% in November. Atlantic storms tend to recurve north or south to miss Cuba, as shown in Figure 4-5. Storms may also originate in the warm waters of the western Caribbean--see the earlier discussion of the TUTT. Storm incidence is least on the eastern end of Cuba, increasing toward the west; storms that do hit eastern Cuba tend to weaken as they cross Hispaniola, which lies near the mean path of storms moving toward Cuba from the east or east-southeast.

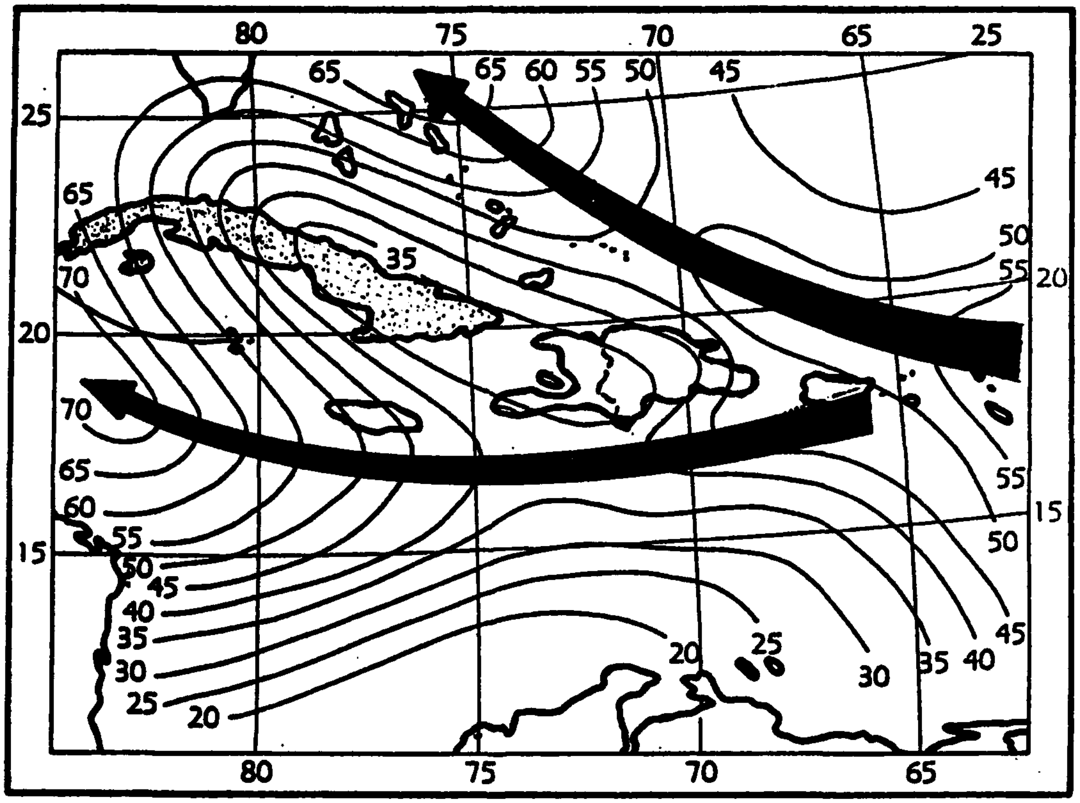


Figure 4-5. Total Number of Hurricanes and Tropical Storms (by 2 1/3-degree Squares) for 72 Years (1886-1957). Arrows show location of maximum storm occurrence frequency.

THUNDERSTORMS. Most locations in Cuba see their maximum thunderstorm activity from June through September. Hail is not generally observed at lower elevations but may occur in the mountains. Mountainous sections of eastern Cuba may see enhanced thunderstorm activity during passage of easterly waves because of orographic uplift.

PRECIPITATION. Annual rainfall amounts are 5-7 inches (127-178 mm) higher on the western side of the island due to the higher incidence of tropical storms and hurricanes there, but some windward exposures on eastern mountain slopes may get as much rain as in the west--see the discussion of dry season precipitation. Most of Cuba has a double precipitation maximum

during the wet season. Most stations see a precipitation maximum in September, October, and early November; there is a secondary maximum in May, followed by a temporary reduction in July caused when a lobe of the Azores High moves over the Caribbean. Pressure falls to its lowest levels of the year after the July lull in rainfall. Exposed locations on the windward side of the Sagua Baracoa Mountains do not follow the "two-season" regime--see the discussion of dry season precipitation.

TEMPERATURES. Mean daily maximums are from the mid 80's (°F) to the low 90's (29-33°C). Mean daily minimums are in the low to mid 70's (22-25°C). Higher elevations can be 10 to 15°F (6-9°C) cooler.

SEA SURFACE TEMPERATURES. Water temperatures have now warmed to 84°F (29°C) and act as a heat source that drives convection and helps sustain tropical storm and hurricane activity.

GENERAL WEATHER. Large-scale flow regains its northeasterly component as the center of the Azores High moves south from its summer position (35° N, 40° W) to its winter position (30° N, 35° W). The trade wind inversion begins to strengthen and lower as the Azores High also migrates south. The result is increased subsidence aloft and increased stability. Convection is suppressed over most of Cuba. In November, polar air masses and associated post-frontal high-pressure systems begin to move south out of the United States and into the Caribbean.

SKY COVER. Mean cloud cover is reduced during the transition, but it is still between 35 and 45% over most of the island. As the trade wind inversion lowers, tops of the dominant cumulus and stratocumulus lower from 8,000-9,000 feet (2.4-2.7 km) to 6,000-8,000 feet (1.8-2.4 km). Cloud bases are still between 2,000 and 3,000 feet (610 and 915 meters).

WINDS. There are no major changes in winds, which continue to be northeasterly at 5-10 knots. Causes of gusty winds change from the infrequent tropical disturbances of summer to the more frequent frontal passages of winter. Again, higher winds are more common on the northwestern end of the island.

THUNDERSTORMS. The average number of days with thunderstorms falls drastically during the transition. Only 1 or 2 days a month now see a thunderstorm, with activity confined to the passage of strong polar outbreaks.

PRECIPITATION. The dry season is *very* dry--mean monthly precipitation is only 1 to 2 inches (25 to 51 mm), compared to 5-7 inches (127-178 mm) in the summer.

TEMPERATURES. Average highs are in the low to mid 80s °F (28° to 30°C). Average lows are between 65 and 70°F (19 and 22°C).

GENERAL WEATHER. Cuba's dry season is dominated by the easterly trade winds that reflect flow around the Azores High. January winds are easterly from the surface to about 15,000 feet (4,573 meters) MSL. Cuba, and especially northwestern Cuba, can also come under the influence of strong transitory highs following the passage of northern hemisphere polar fronts. Heavy cumulus buildups and precipitation can occur along the mountains of extreme eastern Cuba, which are oriented perpendicular to the easterly flow. In undisturbed flow, the trade wind inversion's base is at 7,500 feet (2,287 meters) MSL. Air below the inversion is moist and unstable; above, the air is conditionally unstable but dry. Strong polar outbreaks moving south and southeast from the United States cross Cuba as often as three times a month. Locations in extreme northwestern Cuba (such as Havana) will often bear the brunt of these incursions as they move to the east. Passage of polar fronts can occur into mid-May.

Cuba, like most of the northern West Indies, may see dry season polar frontal passages in stages. After the initial push of cold air moves the front into the region, it tends to become quasi-stationary. At times, another upper-level disturbance may cause a wave to develop on the front, pushing it farther southward. The southward movement can also be caused by a secondary push of polar air from North America. The satellite imagery in Figure 4-6 shows a typical cold front moving through Cuba.

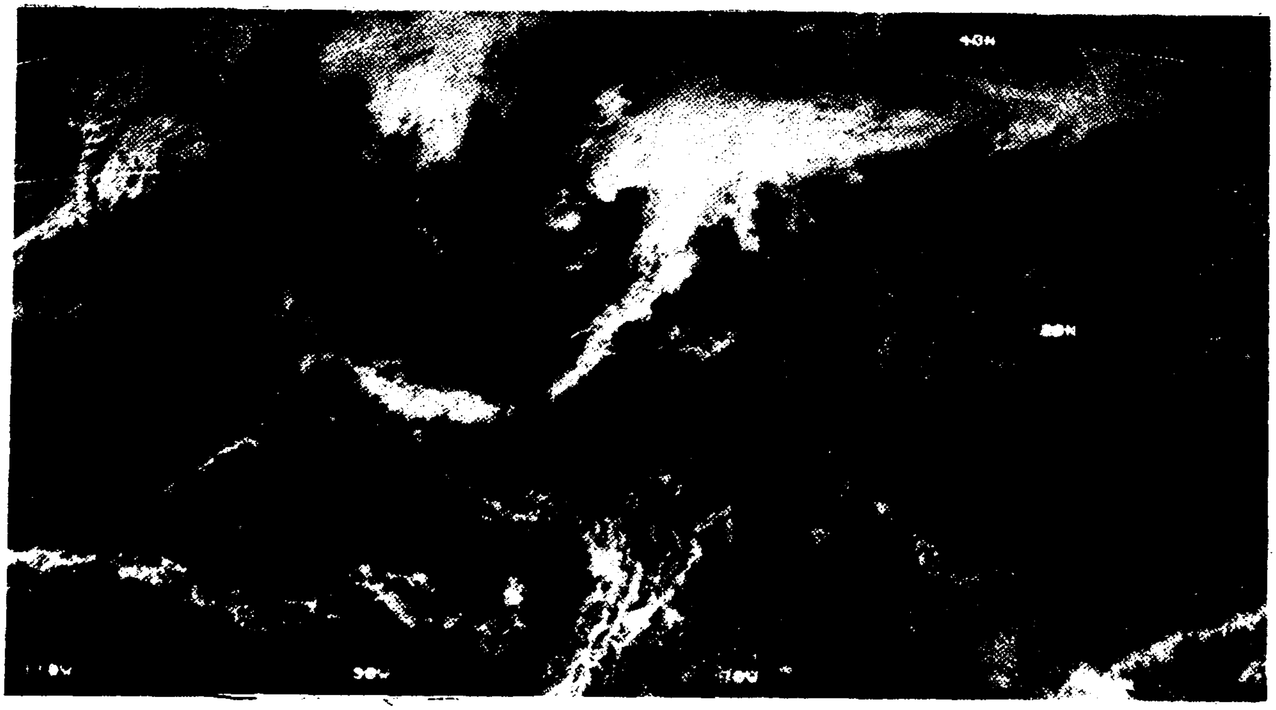


Figure 4-6. GOES Imagery: 1700Z 19 February 1980 Polar Intrusion.

SKY COVER. Cloudiness is at its yearly minimum during the dry season, averaging only 3 to 5 tenths coverage. Ceiling/visibility is below 3,000/3 from 10 to 30% of the time and below 1,000/2 from 5 to 10% of the time. Mountainous or exposed locations see more cloudiness than sheltered locations; afternoons are cloudiest everywhere. Visibilities average better than 6 miles 90% of the time, but sudden showers may restrict ceilings and visibilities to near zero for short periods. Cumulus cloud bases are usually 2,000 to 4,000 feet (610-1,220 meters) with tops at 6,000 to 8,000 feet (1,829-2,439 meters). Some altostratus and cirrus may also be present.

Unstable (originally continental) polar air continues to flow across Cuba for several days after a cold front passage. This results in well-developed stratocumulus and nimbostratus with embedded cumulonimbus possible, especially over northwestern sections of the island. Behind the front, the trade wind inversion typically ruptures and allows convection; heavy cumulus, showers, and isolated thundershowers occur over most of the major mountain ranges. This activity continues until the easterly trades and the trade wind inversion are reestablished. Reduced visibility in fog is infrequent and usually restricted to interior valley locations. Light haze is often present, but it rarely restricts visibility to less than 5 miles. The mean freezing level is at about 15,000 feet (4,573 meters); icing may be found above that level, primarily in towering cumulus and cumulonimbus. Turbulence may be expected in or near convective clouds.

WINDS. The dominant easterly trade winds average 8 to 12 knots, but they can be modified by terrain. Gale force winds (greater than 28 knots) are rare but may accompany stronger polar outbreaks. When the occasional frontal wave forms along a slow-moving polar front in the southwestern Gulf of Mexico, Cuba sees strong southwesterly to westerly winds. In January, the prevailing flow remains easterly up to 15,000 feet (4,573 meters), turns westerly up to 55,000 feet (16,768 meters), and then becomes easterly again.

Land and sea breezes are pronounced. Locations on the southern coast are more prone to local wind effects because the easterly trades are often blocked by mountains. Early morning winds are northerly or northeasterly as cool air drains down out of the mountains. A southerly sea breeze often develops by afternoon.

THUNDERSTORMS. The infrequent dry season convective activity is usually associated with polar outbreaks. Thunderstorms average less than three a month at most locations, but windward mountain slopes may get more. Storms are of short duration but may reduce ceilings and visibilities to near zero for brief periods. Hail is rare, but can occur at higher elevations.

PRECIPITATION. Prolonged rainfall is rare except during passages of the polar front or upper-level troughs, when rains may last for 1 to 3 days. Precipitation amounts on windward and upper leeward slopes are increased due to orographic lifting. Convective clouds that form when winds are forced up windward slopes often move across the peaks and spill over the leeward side. Winds may also be deflected around the sides of the mountains to converge on the upper leeward sides and enhance precipitation. At Baracoa (on the windward side of the Sagua Baracoa Mountains), mean *annual* rainfall is 68 inches (1,727 mm); in contrast, Guantanamo Bay (on the opposite coast in the lee of the mountains) gets only 41 inches (1,041 mm).

TEMPERATURES. Mean daily maximums are in the low 80°F (27-29°C) range; mean daily minimums are in the mid to upper 60's °F (17-20°C). Mountain locations may be 10-15°F (6-9°C) cooler.

SEA SURFACE TEMPERATURES. January sea surface temperatures range from 77°F (25°C) along the northern coast to 80°F (27°C) in the south. The moderating effect of the water helps maintain small yearly temperature variations, particularly on the coasts.

4.1.2 JAMAICA

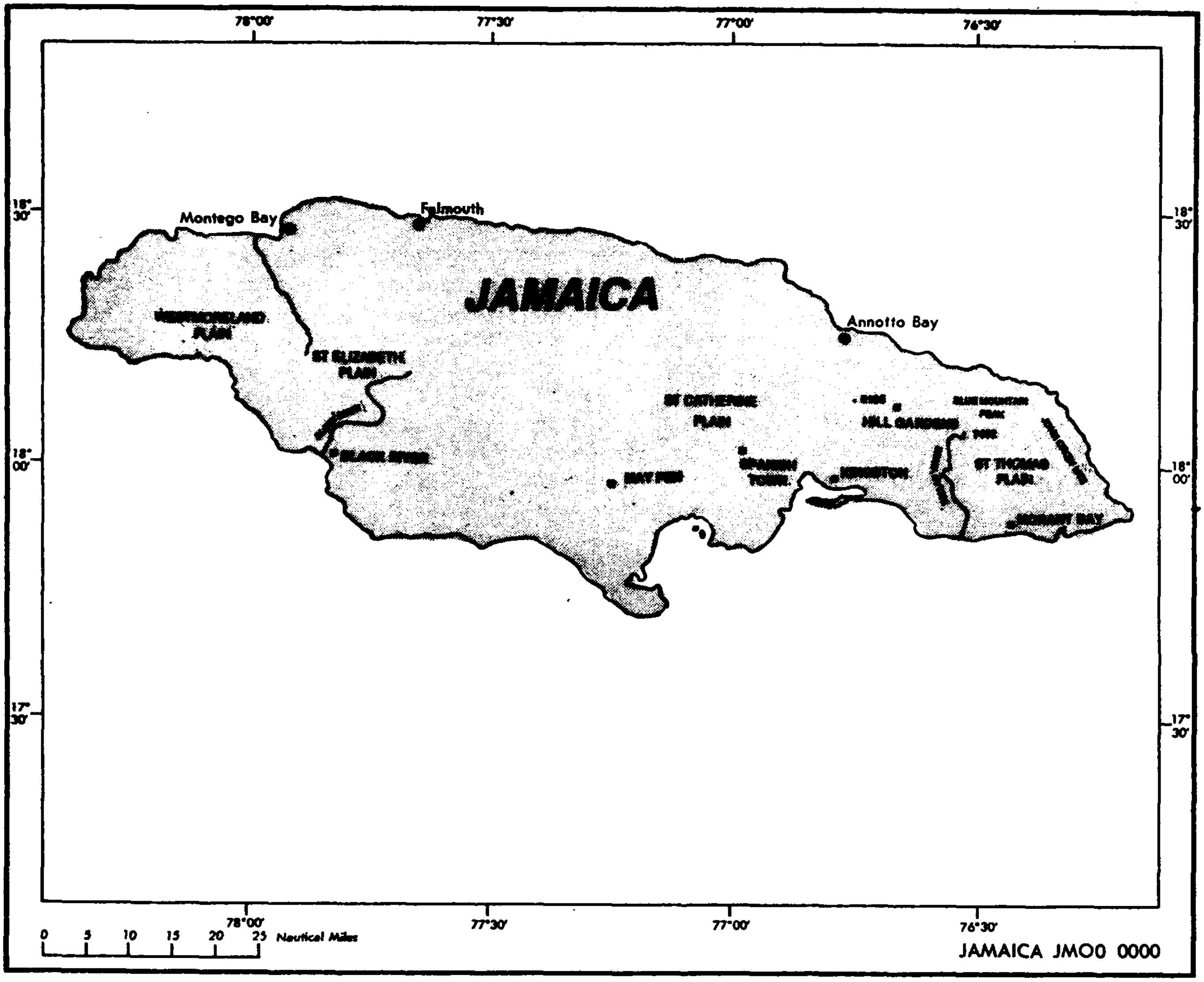


Figure 4-7. Jamaica. Jamaica, an oblong island about 119 miles (220 km) long and 38 miles (70 km) wide, is only about 84 miles (155 km) south of Cuba. Jamaica is mostly rugged, with coastal valleys and plains along the southern coast. Dense rain forests are found in the John Crow Mountains. Cactus and thorn scrub abound in unirrigated parts of the dry south coast, where five well-defined plains are located: the St Thomas Plain, east of Morant Bay; the St Catherine Plain, centered on Spanish Town; the plain of Vere, south of May Pen; the Black River Plains in St Elizabeth; and the Westmoreland Plain. Elevations rise from east to west; most are well above 2,000 feet (610 meters). The most remarkable feature is the 7,402-foot (2,256-meter) peak (Blue Mountain Peak) just east of Kingston, on the eastern side of the island. In the Blue Mountain region, the Yallah River cuts a deep trench several thousand feet deep. In 1692, an earthquake put two-thirds of the city of Port Royal, on the southeast coast, into the sea.

GENERAL WEATHER. In the transition from the dry to the wet season, large-scale flow becomes more easterly than northeasterly. The trade wind inversion begins to weaken and rise as the Azores High migrates north; upper-level subsidence becomes less pronounced. As subsidence lessens, the unstable lower layers become deeper and allow convective precipitation to become more widespread. Polar outbreaks are still possible early in the transition, but their strength and frequency are greatly reduced. Local effects, such as land/sea breezes and mountain/valley winds, become more significant.

SKY COVER. Increased low-level instability is reflected in the slightly higher percentage of ceilings/visibilities below 3,000/3, especially in the afternoon. Frequencies increase from just over 25% in March to more than 30% by May. Cumulus tops now frequently reach to above 10,000 feet (3.1 km).

WINDS. Winds below 20,000 feet (6.1 km) are from the east, but they turn to become southwesterly at higher levels.

THUNDERSTORMS. The mean number of days with thunderstorms increases from an average of 1 in March to more than 3 a month by May.

PRECIPITATION. Instability in the lower levels is again reflected in the increased monthly precipitation totals. By May, average monthly rainfall is nearly 4 inches (101 mm). On the lee side of the Blue Mountains, May rainfall is 10 inches (254 mm), twice that in the sheltered bay at Kingston, south of the mountains.

TEMPERATURES. There is little change from the dry season. Average highs are in the low to mid 80s°F (28 to 30°C), and mean lows are in the low 70s°F (22 to 23°C).

GENERAL WEATHER. By September, the persistent trade winds assume a more east-southeasterly component to bring warmer air into the region. The depth of the low-level trade winds increases. Easterly winds now extend above 25,000 feet (7.6 km) MSL. The northward migration of the Azores High to about 35° N, 40° W results in decreased subsidence aloft and decreased stability. The trade wind inversion becomes weaker and rises to over 9,000 feet (2.7 km), permitting convection to increase. In July, however, the western lobe of the Azores High moves across the West Indies to temporarily raise pressure, increase subsidence and stability aloft, and suppress convection. During this time, Jamaica experiences a "mini dry season."

SKY COVER. Along the northern coast at Montego Bay, afternoon ceilings and visibilities are less than 3,000/3 up to 30% of the time, but slightly less frequent along the southern coast at Kingston (see Figures 4-8a and b). Ceilings and visibilities are never less than 1,000/2 more than 2% of the time at most lower elevations, even when mountains are shrouded in clouds. Sky cover is typically 4 to 5 tenths in cumulus and towering cumulus, but some altostratus and cirrus may be present. Cloud bases are normally 2,000 to 4,000 feet (610 to 1,220 meters) MSL, with tops at 8,000 to 10,000 feet (2.4 to 3.1 km). Passage of a tropical disturbance may produce well-developed nimbostratus and cumulonimbus. Fog is rare, but haze may restrict visibility to 5 miles. Sudden showers may reduce ceilings and visibilities to near zero for brief periods. Icing may be found in clouds above the freezing level, which is about 15,000 feet (4.6 km). Turbulence can be expected in and near convective clouds.

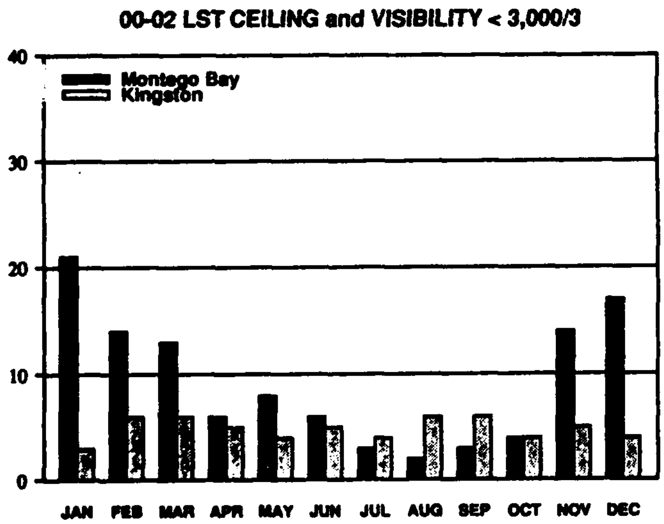


Figure 4-8a. Percent Frequency Ceiling/ Visibility <3,000/3, 00-02 LST, Kingston vs. Montego Bay.

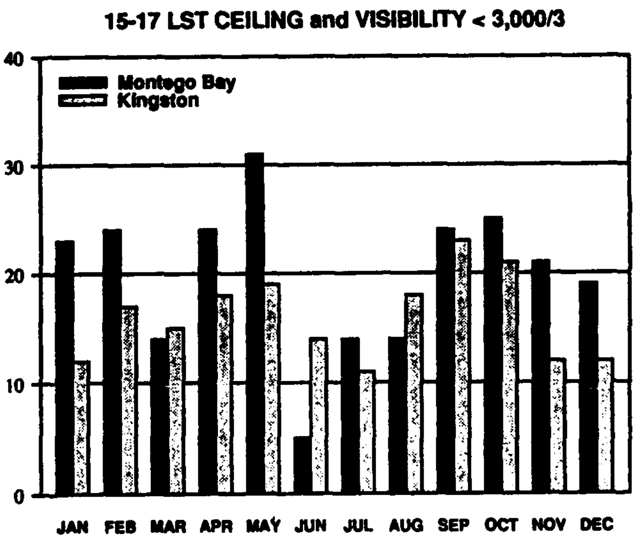


Figure 4-8b. Percent Frequency Ceiling/ Visibility <3,000/3, 15-17 LST, Kingston vs. Montego Bay.

WINDS. Easterly trade winds dominate; mean speed/direction is 8-12 knots from the east-southeast, but terrain can alter the flow. In September, winds are easterly up to 27,000 feet (8,232 meters), backing to northwesterly from 34,000 to 50,000 feet (10.4 to 15.2 km), and returning to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km). The prevailing easterlies often mask local land and sea breezes, particularly on the exposed east coast. But on the west coast, where trade wind flow is blocked by the mountains, the land/sea breeze effect prevails. Interior valleys see mountain breezes at night, as cool air flows down the hills.

TROPICAL DISTURBANCES. Tropical storm and hurricane activity increases through the wet season, with greater frequencies in August, September, and October. Although many tropical disturbances form well off over Atlantic waters before migrating into the Caribbean, others spawn in the warm Caribbean itself (see the discussion of the TUTT in Chapter 2). The mean Atlantic storm track takes them close to Jamaica, as shown in Figure 4-4. But most storms that form in the Caribbean often move north or west, only brushing Jamaica with their outer edges. Even so, rainshowers and gusty winds several hundred miles from the storms' centers may affect the island. Storms that do strike Jamaica often pass over Hispaniola first, where they become much weaker.

THUNDERSTORMS. Thunderstorms are frequent throughout the summer, even in the relatively sheltered area along the southern coast of Jamaica. Kingston's peak month for thunderstorms is September, with 8 thunderstorm days. Mountain locations, especially in eastern Jamaica, can expect more storms due to orographic lifting. Coastal locations have 6-8 a month. Hail at the surface is extremely unlikely, but may be found at higher elevations.

PRECIPITATION. Sudden showers or thunderstorms are the rule. Easterly waves, tropical storms, or hurricanes may bring heavy precipitation for extended periods. Monthly averages are 5 to 8 inches (127 to 203 mm), more in the mountains. Where the Blue Mountains lie perpendicular to the easterly trade winds, orographic lifting enhances precipitation on windward and upper leeward slopes. Hill Gardens has monthly rainfall means of more than 15 inches (381 mm) in October and November. Winds may also flow around the mountains and converge on the leeward side, enhancing precipitation on upper leeward slopes.

TEMPERATURES. "Warm and humid" is the rule during the Jamaican wet season. Mean daily maximums reach 90°F (32°C) at some locations. Mean daily minimums are in the low to mid 70s°F (21-23°C) Temperatures at higher elevations (over 4,500 feet or 1,572 meters) may be as much as 15-20° F (9-12°C) cooler than on the coasts.

SEA SURFACE TEMPERATURES. By now, water temperatures have warmed to 84°F (29°C) and act as a heat source to drive convection and sustain tropical storm and hurricane activity.

GENERAL WEATHER. Large-scale flow regains its northeasterly component as the center of the North Atlantic high moves south from its summer position at 35° N, 40° W to its winter position at 30° N, 35° W. The trade wind inversion begins to strengthen and lower as the North Atlantic High migrates south. The result is increased subsidence aloft and increased stability. Convection is suppressed. In November, polar air masses and associated post-frontal high-pressure systems begin to move south out of the United States and into the Caribbean.

SKY COVER. Mean cloud cover is reduced during the transition, especially at night. Afternoon cumulus with bases between 3,000 and 5,000 feet (915- 1,500 meters) occurs 20-25% of the time, but less than 10% at night. Orographic lifting in the mountains produces more cloudiness. As the trade wind inversion lowers, tops of the dominant cumulus and stratocumulus also lower from 8,000-9,000 feet (2.4 to 2.7 km) to 6,000-8,000 feet (1.8 to 2.4 km).

WINDS. There is a slight change in wind speed and direction, to northeasterly at 5-10 knots. The cause of gusty winds changes from the infrequent tropical disturbances of summer to the more frequent frontal passages of winter.

THUNDERSTORMS. The average number of days with thunderstorms drops drastically. Thunderstorms occur on only 1 or 2 days a month, with activity confined to passage of strong polar outbreaks.

PRECIPITATION. Mean monthly precipitation is only 1 to 2 inches (25 to 51 mm), compared to 5 to 7 inches (127 to 178 mm) in the summer.

TEMPERATURES. Average highs are in the mid to high 80s°F (29 to 31°C). Average lows are in the low 70s°F (22 to 23°C). The mountains are 10-15 degrees cooler throughout the day.

GENERAL WEATHER. Jamaica's dry season is dominated by the easterly trade winds that reflect flow around the Azores High. Winds are easterly from the surface to about 15,000 feet (4,573 meters) MSL in January. In undisturbed flow, the trade wind inversion is based at 7,500 feet (2,287 meters) MSL. Air below the inversion is moist and unstable; the air above is conditionally unstable but dry. Strong polar outbreaks moving south and southeast from the United States can occasionally affect Jamaica, but they are dramatically modified by their long journey across the warm waters of the Gulf of Mexico. Jamaica is sheltered to the north and east by the much larger islands of Cuba and Hispaniola.

Jamaica, like most of the northern West Indies, may see dry season polar frontal passages in stages. The initial push of cold air moves the front over the island, but it becomes quasi-stationary as it moves eastward. Another upper-level disturbance occasionally causes a wave to develop on the front, pushing it farther south. This southward movement can also be caused by a secondary push of polar air from North America.

Passage of a strong polar front typically ruptures the trade wind inversion and allows post-frontal convection. Additional heat and moisture picked up from the Gulf of Mexico and the Atlantic helps in producing heavy cumulus, rain showers, and perhaps thunderstorms over Jamaica. Strong outbreaks, called "Nortes" or "Northers," produce widespread heavy rain and (rarely) gale force winds greater than 28 knots. The southern coast of Jamaica is shielded from the full effects of these systems by the nearby mountains.

The Blue Mountains, on the eastern end of Jamaica, lie nearly perpendicular to the northeast trade winds, resulting in substantially greater rainfall on windward slopes. The higher leeward slopes also get more rainfall when towering cumulus and cumulonimbus (formed as trade winds are forced up the windward slopes) move across the peaks and spill over onto the leeward side. Winds may be deflected around the sides of mountains to converge on upper leeward sides and produce precipitation. The table compares January temperature and precipitation data for Hill Gardens (on the higher leeward slopes of the Blue Mountains) and for Kingston-Norman Manley Airport (on the sheltered southern coast 14 miles southwest of Hill Gardens). It shows the profound differences terrain can have on Jamaican climate:

	HILL GARDENS (*4,897 feet--1,493 meters*)	KINGSTON (*10 feet--3 meters*)
Temperature		
Extreme Maximum	71°F (22°C)	92°F (33°C)
Mean Daily Maximum	66°F (19°C)	86°F (30°C)
Mean Daily Minimum	53°F (12°C)	75°F (24°C)
Extreme Minimum	45°F (07°C)	66°F (19°C)
Precipitation		
Mean	7.0 inches (178 mm)	0.9 inches (23 mm)
Maximum 24-Hour	8.6 inches (218 mm)	1.8 inches (46 mm)
Mean annual	105.5 inches (2,680 mm)	31.5 inches (800 mm)

SKY COVER. Coverage is 3 to 4 tenths along southern coasts and 4 to 5 tenths along northern coasts, but higher in the mountains. At Kingston and along the southern coastal lowlands, ceilings and visibilities are below 3,000/3 about 20% of the time in the afternoon, but less than 10% at other times. Because of its direct exposure to the northeasterly trade winds, afternoon ceilings and visibilities along the northern coast are below 3,000/3 at least 30% of the time, and below 1,000/2 up to 3% of the time. Cloud bases run from 2,000 to 4,000 feet (610 to 1,220 meters); tops are from 6,000 to 8,000 feet (1.8 to 2.4 km). Fog is rare and usually restricted to inland valleys. Light haze is common, but rarely reduces visibility to less than 5 miles. Sudden showers may reduce ceilings and visibilities to near zero for short periods. Icing may be found in clouds (primarily convective buildups) above the freezing level of about 15,000 feet (4.6 km). Turbulence may also be expected in and near towering cumulus and cumulonimbus.

WINDS. Winds are easterly up to 15,000 feet (5.1 km) MSL throughout the dry season. The dominant easterly trades average 6 to 12 knots but can be modified by terrain such as that at Jamaica's eastern end, where low-level winds are turned to the northwest; easterly winds are reestablished above the mountains at 2,000 feet (610 meters). Land and sea breezes are common in Jamaica. The southwestern coast experiences more local breezes because mountains there block the easterly trade winds. Passage of a polar front may produce northerly winds for 1 or 2 days.

THUNDERSTORMS. Dry season thunderstorms are infrequent, averaging only one or two a month. Windward mountain areas can see more. Hail at the surface is extremely rare, but it can occur at higher elevations.

PRECIPITATION. Most precipitation is in brief showers, but during a polar incursion or passage of an upper-level trough, showers and thunderstorms may persist for 1 or 2 days. As mentioned earlier, precipitation is very terrain-dependent. In the Blue Mountains, for example, there is no dry season, per se; rainfall there (5 to 8 inches or 127 to 203 mm a month) is nearly quadruple that of other island locations.

TEMPERATURES can be very comfortable, especially in cooler mountain locations where daily highs and lows might be 15°F (8°C) lower than on the coast. Average highs are in the low 80s °F (28° C), with lows in the low 70s °F (22-23°C). Even extremes are moderate--they range from the low to mid 90s °F (32-34°C) to the upper 50s °F (14 to 14°C).

SEA SURFACE TEMPERATURES in January are 80°F (27°C). The moderating effects of the water help to maintain the small annual temperature variation, particularly along coastlines.

4.1.3 HISPANIOLA

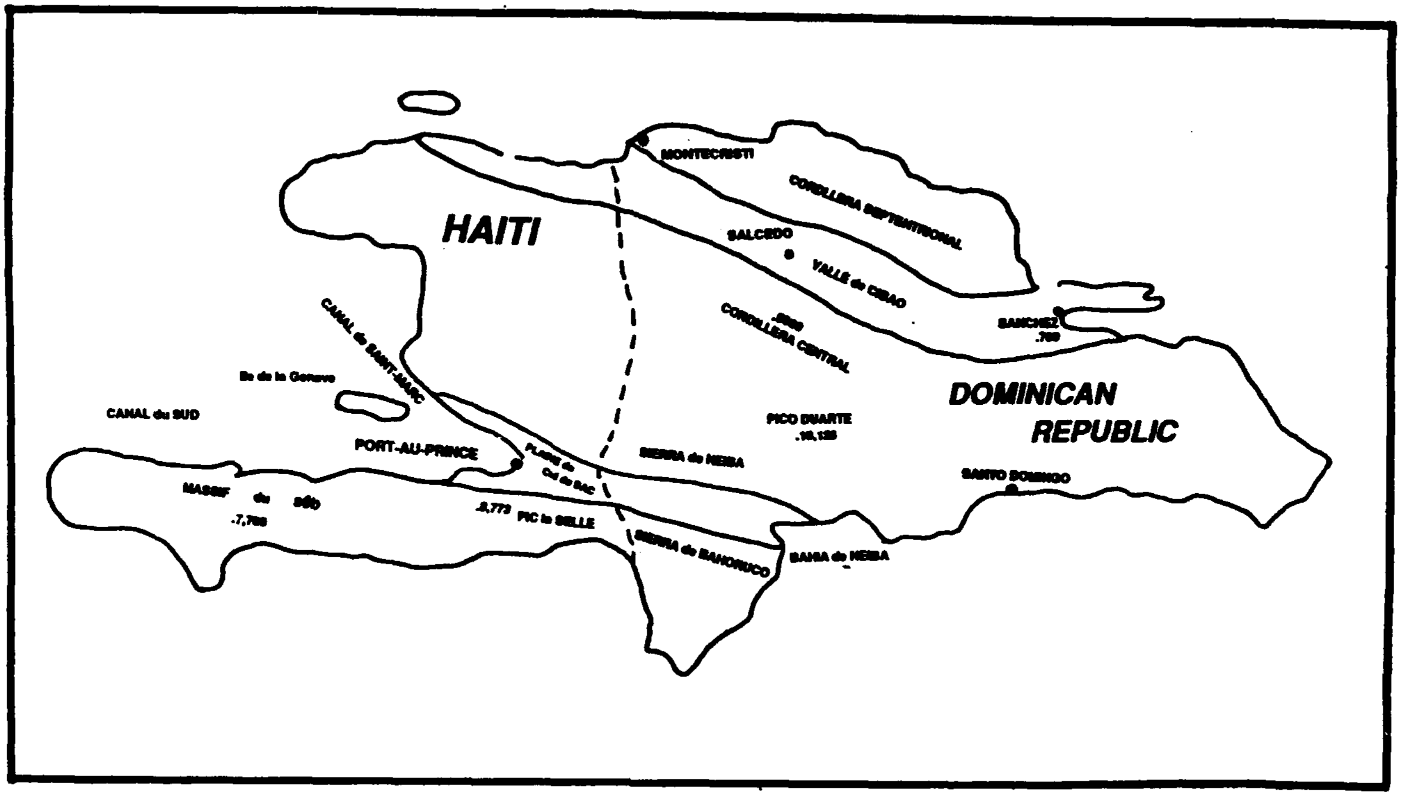


Figure 4-9. Hispaniola (Haiti and the Dominican Republic). Hispaniola lies east of Cuba; it occupies 27,500 square miles. The second largest island in the Greater Antilles comprises Haiti and the Dominican Republic, countries politically separated by a jagged north-south line. Haiti occupies the western third of the island, the Dominican Republic the remaining two-thirds.

HAITI can be described as two peninsulas that resemble a "V" lying on its left side with Port au Prince at its base. The Canal de Saint-Marc washes the northern portion of the "V"; the Canal du Sud, the south. Both are minor features of the Gulf of Gonave. The southern leg of the "V" is ruggedly mountainous, with steeply sloping coastlines. It features the highest peak in Haiti (Pic La Selle, southeast of Port-au-Prince near the Dominican border), with an elevation of 8,773 feet (2,674 meters). Another peak at the other end of the peninsula, in the Massif du Sud, rises to 7,700 feet (2,347 meters). The northern leg of the "V" is less mountainous, with narrow river valley plains that average 1,000 feet (305 meters) between ridges. These smaller hills and mountains average 1,500 to 4,000 feet (457 to 1,219 meters). The northern peninsula is about 80 miles (128 km) wide along the Dominican Republic border, extending westward about 120 miles (222 km) and narrowing to a width of 10 miles (19 km) near the western tip. The southern peninsula extends 180 miles (333 km) westward from the Dominican Republic border and varies in width from 15 to 25 miles (28 to 46 km). Haiti also includes several offshore islands. The largest, Ile de la Gonave, is located in the Gulf of Gonave about 90 km from Port au Prince.

The DOMINICAN REPUBLIC occupies the eastern two-thirds of Hispaniola. The eastern third is mostly a low, flat plain rising northward to rolling hills that average slightly over 1,000 feet (305 meters). The western two-thirds of the country is divided by four mountain ranges oriented west-northwest and east-southeast; from north to south, these ranges are the Cordillera Septentrional, Cordillera Central, Sierra de Neiba, and Sierra de Bahoruco. Lying between the Cordillera Septentrional and the Cordillera Central is a broad valley (Valle de Cibao) that extends from Montieristi to Sanchez and rises from sea level at each end to near 700 feet (213 meters) at Sanchez. Its rivers drain the northern half of the country. The whole central part of the Cordillera Central extends to above 5,000 feet (1,524 meters). Pico Duarte is the highest peak, with an elevation of 10,128 feet (3,087 meters), the highest in the West Indies. Rugged upland valleys are cut deeply by fast running streams between the Cordillera Central and the Sierra de Neiba. A low valley stretches westward from Bahia de Neiba between the Sierra de Neiba and the Sierra de Bahoruco. Santo Domingo is on the south central coast.

GENERAL WEATHER. Large-scale flow becomes more easterly than northeasterly. The trade wind inversion begins to weaken and rise as the Azores High moves north. Upper-level subsidence becomes less pronounced. As subsidence lessens, the unstable lower layers become deeper, allowing convective precipitation to become more widespread over Hispaniola. The northern coasts see what amounts to a second wet season during April and May. This can be attributed to the strengthening of the land/sea breeze as temperatures rise while the trade-wind inversion is still weak. Convergence of local winds with trade wind flow can occur along northern coasts.

SKY COVER. Increased low-level instability is reflected in the slightly higher percentage of ceilings/visibilities below 3,000/3, especially in the afternoon. The northern coast's "mini wet season" is shown by comparing May ceiling/visibility at Port-au-Prince in southern Haiti (below 3,000/3 less than 10% of the time) with Puerto Plata along the northern coast of the Dominican Republic, where ceiling/visibility is below 3,000/3 at least 30% of the time. There is an afternoon cloud cover maximum throughout Hispaniola; afternoon cumulus bases are between 5,000 to 7,000 feet (1.5 to 2.1 km).

WINDS. Low-level winds are from the east below 20,000 feet (6.1 km), but southwesterly at higher levels.

THUNDERSTORMS. The most noticeable change during the dry-to-wet transition is the sharp increase in convection. Thunderstorm days at many locations increase from 2 or 3 in April to 8-10 in May.

PRECIPITATION. Low-level instability is reflected in increased monthly precipitation totals. Hispaniola's rugged terrain produces a wide range of monthly mean precipitation amounts in all seasons. By May, mountain stations average more than 10 inches (254 mm). At other locations, rainfall often doubles between April and May, to between 5 and 7 inches (127 to 178 mm).

TEMPERATURES. There is little change in mean temperature from the dry season. Average highs are from the mid to high 80s°F (30 to 32°C). Lows are in the low 70s°F (22 to 23°C). Mountain locations average from 10-15°F (5.5-8°C) cooler.

GENERAL WEATHER. Hispaniola lies in the band of persistent trade winds throughout the wet season. In undisturbed air, convection from orographic lift over rugged terrain occurs daily. Tropical disturbances are frequent visitors. Unlike Cuba and Jamaica (which Hispaniola protects), the island must bear the full fury of mature tropical disturbances that move westward across the Atlantic. The easterly wave, however, is the most frequent disturbance here. These disturbances are usually very deep, extending from the surface to above 15,000 feet (4.6 km). In September, the persistent trade winds assume a more east-southeasterly component to bring warmer air into the region. The depth of the low-level trade winds increases. Easterly winds now extend above 25,000 feet (7.6 km) MSL. The northward migration of the Azores High (to about 35° N, 40° W) results in decreased subsidence aloft and decreased stability. The trade wind inversion weakens and climbs to over 9,000 feet (2.7 km), allowing increased convection. In July, however, the western lobe of the Azores High moves across Hispaniola to temporarily raise pressure, increase subsidence and stability aloft, and suppress convection. Many parts of Hispaniola experience a "mini dry season" at this time.

SKY COVER. Sky cover is generally 4 to 7 tenths of cumulus and towering cumulus. Some mid- and upper-level clouds may also be present. Clouds build in the afternoon due to convective heating. Ceilings and visibilities are below 3,000/3 from 10 to 30% of the time at most locations. Stations along the northeast coast and on the windward side of the Cordillera Septentrional mountains may see ceilings and visibilities below 3,000/3 more than 40% of the time--see Figures 4-10a and 4-10b for north-south and diurnal comparisons. Ceilings and visibilities are rarely below 1,000/2 anywhere except at windward mountain locations. Sudden showers may reduce ceilings and visibilities to near zero for brief periods. Cloud bases are typically 2,000 to 4,000 feet (610 to 1,220 meters) MSL with tops at 8,000 to 10,000 feet (2.4 to 3.1 km) MSL. Cumulonimbus tops may reach 50,000 feet (15.2 km). Fog is rare, but may form in interior valleys and in the mountains where clouds lie against the slopes. Light haze is often present but rarely restricts visibility to less than 5 miles. Icing can be expected in clouds above the freezing level, which lies at about 15,000 feet (4.6 km) MSL. Expect turbulence in and near convective clouds.

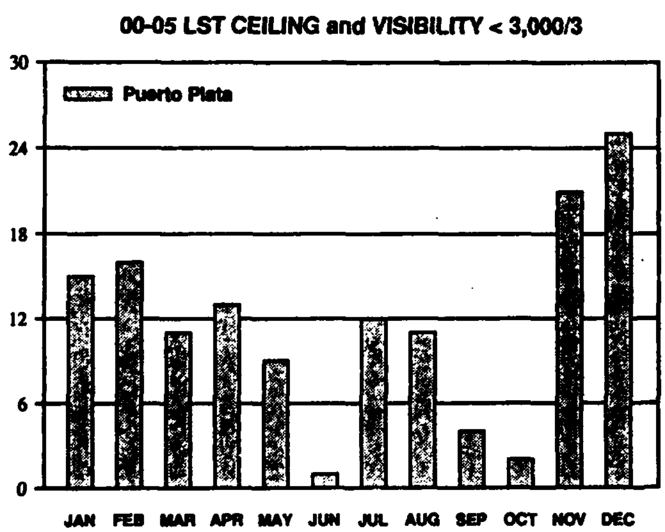


Figure 4-10a. Percent Frequency Ceiling/ Visibility <3,000/3, 00-05 LST, Puerto Plata, Dominican Republic. Port au Prince data not available.

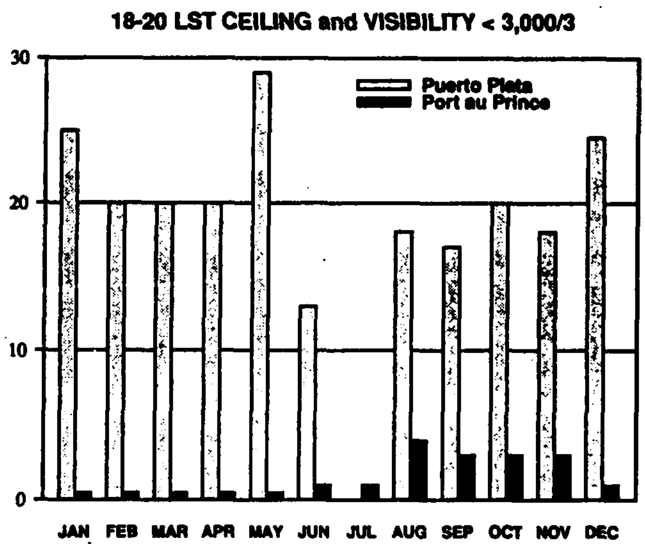


Figure 4-10b. Percent Frequency Ceiling/ Visibility <3,000/3, 18-20 LST, Puerto Plata vs. Port au Prince, Haiti.

WINDS. In September, upper winds are east-southeasterly up to 25,000 feet (7.6 km) MSL. They veer to the south at 28,000 feet (8.5 km), then turn to westerly or west-northwesterly from 30,000 to 50,000 feet (9.1 to 15.2 km), returning to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km) MSL. Surface winds are easterly with mean speeds ranging from 9 knots in the interior and along the western coast to 14 knots along the other coasts. Local terrain influences can modify mean flow. Land and sea breezes are common. At Santo Domingo, on the south coast of the Dominican Republic, mean surface winds are out of the north as the easterly trades are deflected by the Cordillera Oriental and western Cordillera Central mountains, oriented west-northwest to east-southeast. At Sabana De La Mar, mean winds are southerly as a result of deflected trade winds, enhanced land breeze, and downslope winds from the Cordillera Oriental.

TROPICAL DISTURBANCES. Tropical storm and hurricane activity increases through the wet season, reaching a peak in August, September, and October. Storms are least frequent at the beginning and end of the wet season; only 4% occur in May, 5% in November. The eastern portion of the Dominican Republic often takes the full force of tropical storms and hurricanes as they move westward from the Atlantic. Haiti, on the western part of the island, is spared as most storms weaken by moving through and across the mountains of The Dominican Republic. Southern portions of the island are more vulnerable to storms approaching from the southeast; when "Emily" crossed Hispaniola on September 22, 1987, she came on shore near Barahona, Dominican Republic, with 100 mph winds. Weakening as she crossed the mountains to the north coast of Haiti, Emily was only capable of 65 mph winds the next morning when she reentered the Caribbean.

THUNDERSTORMS are very frequent; although often associated with tropical disturbances or easterly waves, air mass thunderstorms are certainly possible. Sheltered locations such as Port-au-Prince can expect 15-20 days with thunderstorms during the wet season; lee side mountain locations can have even more. Tops easily rise to over 50,000 feet (15.3 km). Turbulence is a danger with any type of thunderstorm. Hail at the surface is highly unlikely but may occur at the highest elevations.

PRECIPITATION usually falls as sudden showers in thunderstorms of short (less than 1/2 hour) duration, but the passage of easterly waves, tropical storms, and hurricanes may bring heavy rainfall lasting for several days. Interior locations tend to be much drier than exposed, windward, and mountain locations. Mean monthly precipitation in interior locations is 6 to 8 inches (152 to 203 mm). In other areas, it is well over 10 inches (254 mm) a month. An interesting phenomenon occurs in the Valle de Cibao, where the eastern end of the valley (east of Salcedo) slopes upward and is under the influence of almost uninterrupted easterly trade wind flow, producing abundant rainfall from orographic lift. The largest percentage of the population of the Dominican Republic lives in this part of the valley. West of Salcedo, the valley slopes downward to the ocean at Montecristi; sheltered, this portion has much less rainfall.

TEMPERATURES. Hispaniola is hot and humid throughout the wet season. At lower elevations, mean daily maximums are from the mid 80's to the mid 90's°F (29-34°C). Mean daily minimums range from the mid 60's to mid 70's°F (19-25°C). Mountain locations can be 10°F (6°C) cooler.

SEA SURFACE TEMPERATURES. Waters that have warmed to 84°F (29°C) act as a heat and moisture source to drive convection and sustain tropical storm and hurricane activity.

GENERAL WEATHER. Large-scale flow regains its northeasterly component as the center of the Azores High moves south from its summer position at 35° N, 40° W to its winter position at 30° N, 35° W. The trade wind inversion begins to strengthen and lower as the North Atlantic High migrates south; the result is increased subsidence aloft and increased stability. Convection is suppressed over most of Hispaniola. In November, polar air masses and associated post-frontal high-pressure systems begin to move south out of the United States and into the Caribbean.

SKY COVER. Mean cloud cover during the transition drops to 25-35% over most of the island. As the trade wind inversion lowers, the cloud tops of the dominant cumulus and stratocumulus go from 8,000-9,000 feet (2.4-2.7 km) to 6,000-8,000 feet (1.8-2.4 km). Cloud bases remain between 2,000 and 3,000 feet (610 and 915 meters).

WINDS. There are no major changes in surface flow, which is still easterly at 5-10 knots. There is a reduction in frequency of gusty winds as tropical disturbances and easterly waves become less common.

TROPICAL DISTURBANCES. Frequency of tropical storms and hurricanes decreases sharply in November as sea surface temperatures cool and the Azores High moves southward.

THUNDERSTORMS. The average number of days with thunderstorms falls drastically to only 1 or 2 a month.

PRECIPITATION. The dry season sets in somewhat later in the northern part of Hispaniola, where monthly rainfall averages don't drop below 5 inches (127 mm) until January. Mountain locations have to wait until well into the dry season before monthly precipitation averages drop appreciably.

TEMPERATURES. Average highs are in the low to mid 80s°F (27 to 29°C). Average lows are in the high 60s to low 70s°F (20 to 22°C).

GENERAL WEATHER. Hispaniola's dry season is dominated by the easterly trades that result from flow around the Azores High. In January, winds are easterly from the surface to near 15,000 feet (4.6 km) MSL. Hispaniola is far enough east to come under the influence of strong transitory highs that follow the passage of polar fronts from North America, as well as of migratory highs on the western part of the Azores High. The fronts and the cold anticyclones that follow them, however, have been greatly modified by the time they reach Hispaniola. A day or two of cloudy skies, light rain, and cooler temperatures are followed by increased pressure and cloudless skies. Hispaniola can be viewed as a graveyard for most fronts that reach it. Fronts that cause light rain in Haiti, for example, may not have enough force left to cause more than a slight wind shift in the Dominican Republic. In undisturbed flow, the trade wind inversion is based at 7,500 feet (2.3 km) MSL. Air below the inversion is moist and unstable; air above is conditionally unstable, but dry. Strong polar outbreaks moving south and southeast from the United States can disrupt this inversion for a day or two, allowing an increase in cloudiness. Hispaniola, like most of the northern West Indies, may see dry season polar front passages in stages. The initial push of cold air moves the front into the region, but as it moves eastward it becomes quasi-stationary. A second upper-level disturbance can cause a wave to develop on the front and push it farther south. This southward movement can also be caused by a secondary push of polar air from North America.

SKY COVER. Cloud cover is generally 3 to 5 tenths of cumulus and trade wind stratocumulus. Ceilings and visibilities are below 3,000/3 up to 40% of the time at windward coastal locations, but higher in the mountains. Forced uplift of the trade winds over the larger mountains on Hispaniola produces heavy cumulus. In inland valleys, ceilings and visibilities are less than 3,000/3 only 5% of the time. Ceilings and visibilities drop below 1,000/2 no more than 2% everywhere except in windward mountain locations. Cloud bases are usually 2,000 to 4,000 feet (610 to 1,220 meters) MSL; tops range from 6,000 to 8,000 feet (1.8 to 2.4 km) MSL. Fog is uncommon but may form at isolated coastal locations, in interior valleys, or along mountain slopes. Light haze is common but rarely limits visibility to less than 5 miles. Precipitation in sudden showers may reduce ceilings and visibilities to near zero for short periods. Passage of a polar front may bring 1 or 2 days of convective cloudiness and showers. The freezing level is usually near 15,000 feet (4.6 km) MSL; icing may be encountered above. Turbulence may also be expected in and near convective clouds.

WINDS. January upper-level winds remain easterly to 15,000 feet (4.6 km), backing from northerly at 18,000 feet (5.5 km) to westerly or west-northwesterly from 23,000 to 50,000 feet (7.0 to 15.2 km), then returning to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km). Mean surface winds are easterly at 8 to 10 knots along the western and interior sections of the island, and 11 to 13 knots along the coasts. Mean direction is east-northeasterly along the northern coast, easterly elsewhere. Passage of a polar front, however, may bring northwesterly winds for 1 or 2 days. Many areas experience local modification of winds due to topography--see the discussion on land/sea breezes. Since Dominican Republic mountain ranges lie nearly parallel to the easterly trades, "funnelling" of winds in east-west valleys is common, especially in the valley between the Sierra de Neiba and Sierra de Bahoruco mountains along Lake Enriquillo. Locations on the western coast, where the easterly trade winds are often blocked by mountains, are more prone to local breezes. Port-Au-Prince, Haiti, often sees a westerly sea breeze from late morning through late afternoon. Locations on the southern coast have southerly sea breezes during the day. Interior valleys and locations near mountains on the southern and western coasts may have a land breeze at night as cool air flows down the mountain slopes.

THUNDERSTORMS. Thunderstorms occur 2 days a month or less at most locations, but windward mountain slopes may see more. Hail at the surface is highly unlikely but may occur at high mountain locations.

PRECIPITATION. Most rainfall is in brief showers, but polar incursions may produce activity lasting for 1 or 2 days. Coastal locations throughout Hispaniola average less than 2 inches (51 mm) a month. There is more rain in the Cordillera Central and the Cordillera Septentrional, however, where monthly rainfall averages 5 to 7 inches (127 to 178 mm). The Cordillera Central also has a significant effect on the weather of central Haiti as it blocks the easterly trade winds; subsiding air on the leeward side of the range drops mean December-February precipitation to less than 1 inch (25.4 mm) a month.

TEMPERATURES. Mean daily maximums at lower elevations range from 82 to 90°F (28-32°C). Mean daily minimums are 60-72°F (16-22°C). Mountain locations are cooler. Constanza (elevation 4,072 feet/1.2 km) in the Dominican Republic sees mean daily maximums of 74-76°F (24°C) and mean daily minimums of 46-54°F (08-12°C). Constanza has recorded an extreme minimum of 32°F (0°C).

SEA SURFACE TEMPERATURES. Sea surface temperatures in January are 80°F (27°C). The moderating effects of the warm water help to maintain small annual temperature variations, especially along the coastlines.

4.1.4 PUERTO RICO

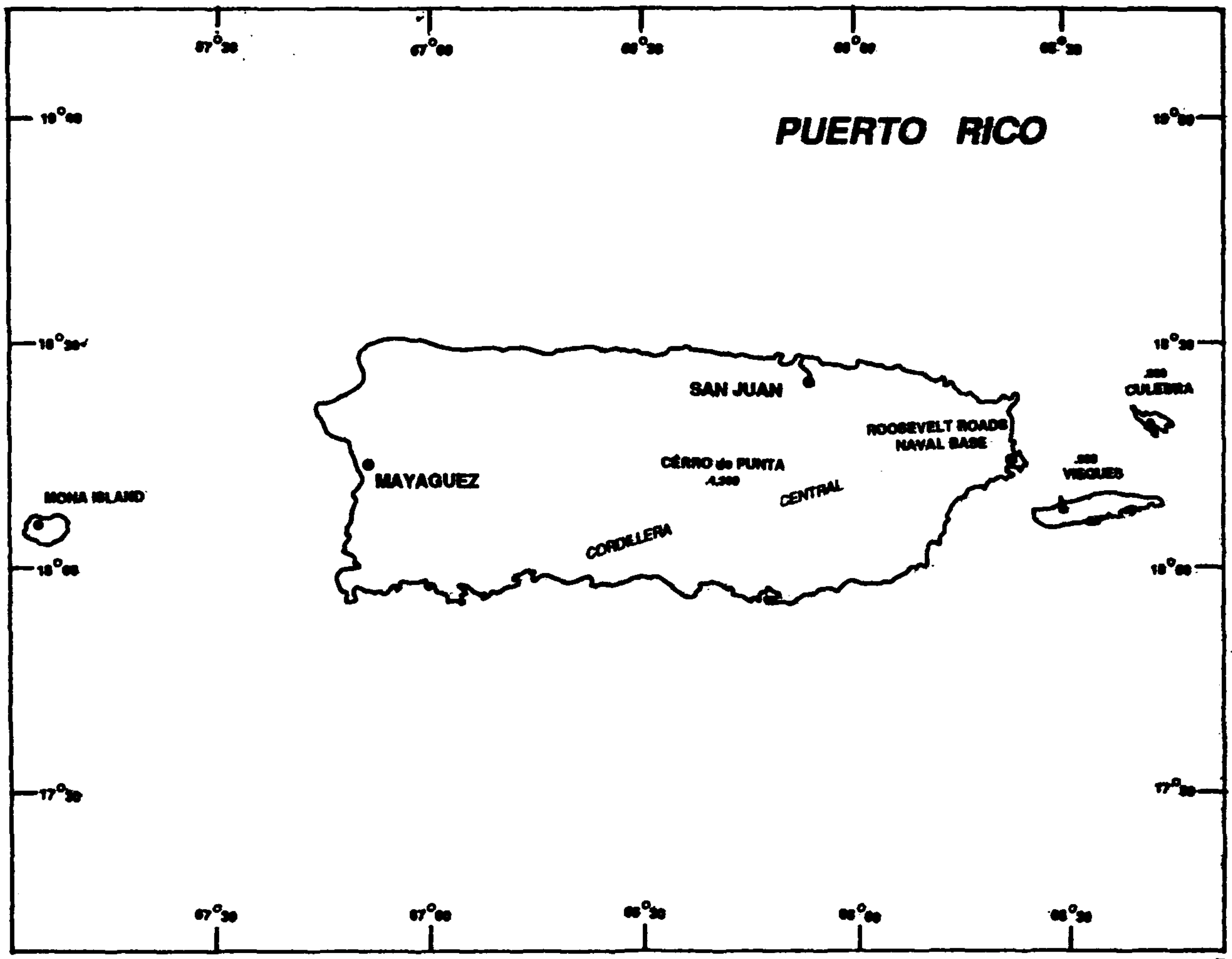


Figure 4-11. Puerto Rico. At 3,423 square miles, Puerto Rico is the third largest island in the Greater Antilles. It is 70 miles (130 km) due east of Hispanola. San Juan is on the northeast coast. Coastal plains average 200 to 500 feet (61 to 152 meters), but foothills of 1,000 to 1,200 feet (305 to 366 meters) are found farther inland. An east-west mountain range (the Cordillera Central) stretches the entire length of the island. Elevations average 3,000 feet (914 meters), but there are some peaks over 4,000 feet (1,219 meters). Cerro de Punta, in the approximate center of the island, is the highest peak at 4,390 feet (1,338 meters). The small islands of Vicques (988 feet--301 meters) and Culebra (660 feet--201 meters) lie about 10 and 15 miles (19 and 28 km), respectively, off the eastern coast and the Roosevelt Roads Naval base. Mona Island lies about 32 miles (60 km) off the western coast and Mayaguez. Elevations are shown in feet.

GENERAL WEATHER. Large-scale flow becomes more easterly than northeasterly. The trade wind inversion begins to weaken and rise as the Azores High migrates north; upper-level subsidence becomes less pronounced. As subsidence lessens, the unstable lower layers become deeper, allowing convective precipitation to become more widespread over Puerto Rico.

SKY COVER. There is a general increase in cloud cover over the island during the transition. This is reflected by the slightly higher percentage of ceilings/visibilities below 3,000/3, especially in the afternoon, when frequencies go to 20-25%. The southern coast of Puerto Rico, however, is still well protected by the Cordillera Central; frequency of ceiling/visibility below 3,000/3 there is only 3-5%.

WINDS. Winds below 20,000 feet (6.1 km) are from the east, becoming westerly above.

THUNDERSTORMS. The number of thunderstorm days increases from 1-3 in April to 6-8 by May.

PRECIPITATION. Puerto Rico's rugged terrain guarantees a wide range of monthly mean precipitation amounts. Several stations on the western end of the island have a "mini wet season" during April and May, when they average more than 10 inches (254 mm) of rain a month, the highest precipitation amount in all Puerto Rico. It is unclear what causes this anomaly. Expect considerably higher rainfall amounts in the mountains.

TEMPERATURES. There is little change in the mean temperature. Average highs run from the mid to high 80s°F (29 to 31°C). Mean lows are in the low 70s°F (22 to 23°C). Mountain locations are 10-15 degrees cooler.

GENERAL WEATHER. Puerto Rico lies in the band of persistent trade winds throughout the wet season. In undisturbed air, convection occurs on a daily basis, caused by orographic lifting over rugged terrain. Tropical disturbances are frequent visitors. Unlike Cuba and Jamaica, which are protected by Hispaniola, Puerto Rico must bear the full fury of mature tropical disturbances moving westward across the Atlantic. The easterly wave, however, is the most frequent disturbance to affect the island. These are usually very deep, often extending from the surface to above 15,000 feet (4.6 km). In September, the persistent trade winds assume a more east-southeasterly component, bringing warmer air into the region. The depth of the low-level trade winds increases. Easterly winds now extend above 25,000 feet (7.6 km) MSL. The northward migration of the Azores High (to about 35° N, 40° W) results in decreased subsidence aloft and decreased stability. The trade wind inversion becomes weaker and rises to over 9,000 feet (2.7 km), permitting convection to increase. During July, however, the western lobe of the Azores High moves across Puerto Rico to temporarily raise pressure, increase subsidence and stability aloft, and suppress convection. Many parts of Hispaniola experience a "mini dry season" at this time.

Even though they are rare, waterspouts and tornadoes can occur in Puerto Rico. Waterspouts have been observed in the Passage De Vieques off the Eastern coast. Most stay off shore, but some have moved inland. In 1980 such a funnel cloud touched down in Officers' housing at Roosevelt Roads Naval Air Station, where it caused minor damage.

SKY COVER. Cloud cover is about 5 to 7 tenths with cumulus the favored type. Bases are normally 2,000 to 4,000 feet (610 to 1,220 meters) MSL, with tops at 8,000 to 10,000 feet (2.4 to 3.1 km) MSL. Towering cumulus and cumulonimbus build during the afternoon. Ceilings/visibilities are below 3,000/3 up to 30% of the time, but at most locations are never below 1,000/2 more than 2% of the time. Lower ceilings and visibilities are normally due to sudden heavy showers that persist only briefly. Fog is rare and normally confined to interior valleys. Ceilings and visibilities may be considerably lower at mountain locations. Light haze is common but rarely restricts visibility to less than 5 miles. The freezing level is at about 15,000 feet (4.6 km) MSL; expect icing in clouds above, especially in convective buildups. Expect turbulence in and near convective buildups.

During the wet season, Puerto Rico sees an unusual cloud phenomenon caused by the sea breeze. As the sea breeze sets up, orographic uplift causes large cumulus clouds to build over the interior mountains. The upper-level subsidence of the sea breeze cell is found just offshore, where it hinders development of tradewind cumulus over open waters. In such situations, larger islands such as Puerto Rico see an odd ring of clear air encircling them. Figure 4-12 shows how this phenomenon occurs.

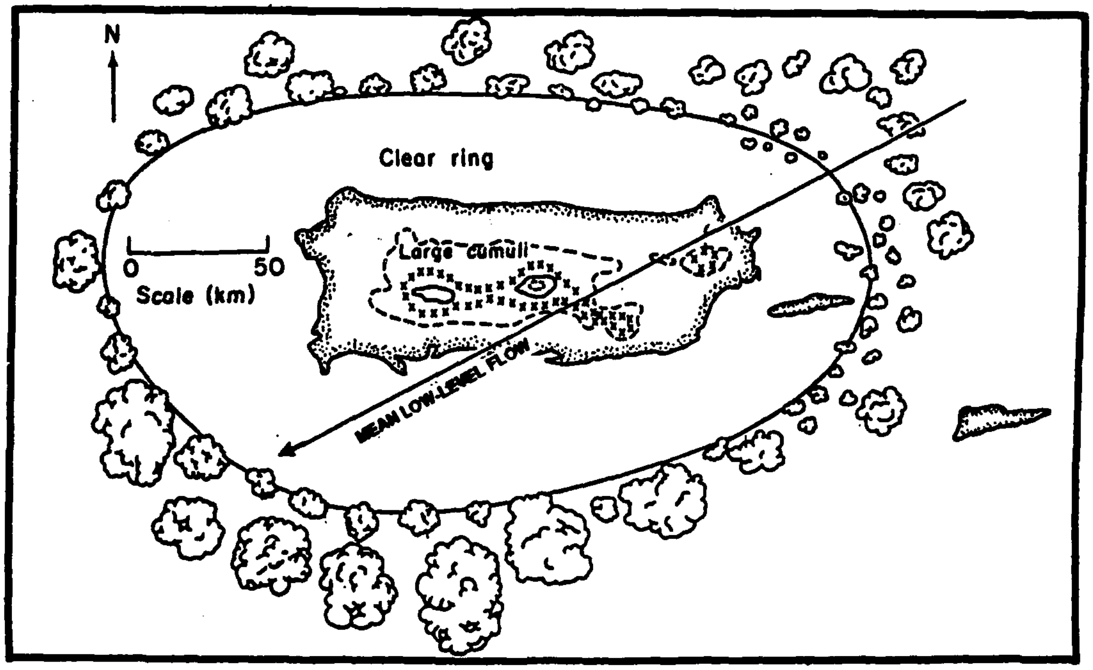


Figure 4-12. Clear Ring Around Puerto Rico. An effect of the sea breeze on large islands.

WINDS. Easterly trade winds dominate the wet season, averaging 12 to 14 knots. In September, winds are easterly through 25,000 feet (7.6 km) MSL. They veer through southerly to southwesterly at 30,000 feet (9.2 km), westerly at 40,000 feet (12.2 km), and northwesterly at 50,000 feet (15.2 km). Winds return to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km). Land and sea breezes are a daily feature of the wet season. Along the western coast (where the easterly trades are blocked by the central mountains) there is a westerly sea breeze during the afternoon. Interior locations at the bases of mountains see mountain breezes at night as cool air flows down the slopes.

TROPICAL DISTURBANCES. Activity increases through the wet season, peaking in August, September, and October. Many tropical disturbances form well out into the Atlantic and migrate into the Caribbean (see figure 4-5). Easterly waves begin to cross the Caribbean late in May, increasing in number as the wet season progresses. Associated weather ranges from increased cloudiness to heavy showers and thunderstorms with heavy rainfall along (and behind) the wave; 8 inches (203 mm) in 24 hours has been observed. Passage of an easterly wave can be expected every 4 or 5 days. Low-level trade wind surges in the easterlies also move through the Caribbean frequently during the wet season; associated weather ranges from increased cloudiness to showers and thunderstorms. The mountains in eastern Puerto Rico may see enhanced convection due to orographic uplift.

THUNDERSTORMS. This is not just the wet season in Puerto Rico; it is the thunderstorm season as well. Thunderstorm activity increases throughout the wet season, averaging 5-10 a month. Although most thunderstorms are associated with tropical disturbances or easterly waves, air mass thunderstorms can occur, especially over the mountains. Hail at the surface is highly unlikely, but it may occur in the higher elevations in severe storms.

PRECIPITATION. Rainshowers and thunderstorms (all of short duration) are common. Windward mountain slopes get much more precipitation than interior, leeward locations. Extended periods of precipitation are usually limited to the passage of easterly waves, tropical storms, and hurricanes. The wettest part of Puerto Rico is on the Northeast coast in the Luquillo mountains, which rise to over 3,000 feet (915 meters) MSL. Average rainfall at some locations is as much as 180 inches (4,572 mm) a year; some years record 250 inches (6,350 mm).

TEMPERATURES. Mean maximum temperatures run from the low 80's to low 90's°F (28 to 33°C). Mean minimum temperatures are in the mid-60 to mid-70°F (18 to 24°C) range. Mountain locations may average 10°F (6°C) less.

SEA SURFACE TEMPERATURES. Water temperatures warm to almost 84°F (29°C) and act as a heat source to drive convection and sustain tropical storm and hurricane activity.

GENERAL WEATHER. Large-scale flow regains its northeasterly component as the center of the North Atlantic high moves south from its summer position (35° N, 40° W) to its winter position (30° N, 35° W). The trade wind inversion begins to strengthen and lower as the North Atlantic high migrates south. The result is increased subsidence aloft and increased stability. Convection is suppressed over most of Hispaniola. In November, polar air masses and associated post frontal high-pressure systems begin to move south out of the United States and into the Caribbean.

SKY COVER. Although mean cloud cover decreases during the transition, it remains between 15-25% over most of the island. As the trade wind inversion lowers, the cloud tops of the predominant cumulus and stratocumulus lower from 8,000 to 9,000 feet (2.4 to 2.7 km) to 6,000 to 8,000 feet (1.8 to 2.4 km). Bases remain between 2,000 to 3,000 feet (610 to 915 meters). Along the northern and eastern coasts of the island there are periods of early morning clouds, with ceilings between 2,000 to 3,000 feet (610 to 915 meters). This cloud cover is probably caused by convergence between the trade winds and a land breeze/mountain wind combination. Clouds usually dissipate by late morning.

WINDS. There are no major changes in wind speed or direction, which remain easterly at 5-10 knots. There is a reduction in frequency of gusty winds as tropical disturbances and easterly waves become less of a factor.

THUNDERSTORMS. The average number of days with thunderstorms falls drastically, to 1-2 a month.

PRECIPITATION. The dry season sets in somewhat later in the northern and eastern parts of Puerto Rico due to orographic lifting of the easterly trade winds. Monthly precipitation averages do not drop below 5 inches (127 mm) until January. Mountain locations have to wait until well into the dry season before monthly precipitation averages drop appreciably.

TEMPERATURES. Average highs are in the low to mid 80s°F (27 to 29°C). Average lows are in the high 60s to low 70s°F (20 to 23°C).

GENERAL WEATHER. The Puerto Rican dry season is dominated by the easterly trade winds that reflect flow around the Azores High. Winds are easterly from the surface to about 15,000 feet (4.5 km) MSL in January. Puerto Rico is far enough east to come under the influence of strong transitory highs moving southeast across the Atlantic, but these fronts can rarely be identified as such by the time they reach Puerto Rico. In undisturbed flow, the trade wind inversion is based at 7,500 feet (2.3 km) MSL. Air below the inversion is moist and unstable; the air above is conditionally unstable, but dry.

Puerto Rico, like most of the northern West Indies, may see dry season polar front passages in stages. The initial push of cold air moves the front into the region, but as it moves eastward, it becomes quasi-stationary. At times, a second upper-level disturbance causes a wave to develop on the front and pushes it farther south. The southward movement can also be caused by a secondary push of polar air from North America.

SKY COVER. Ceilings and visibilities are good. Cloud cover is typically 3 to 5 tenths cumulus, but ceilings and visibilities are better than 3,000/3 fully, 80% of the time and less than 1,000/2 only 1% of the time. Mountain locations can be cloudier. Cloud bases are typically 2,000 to 4,000 feet (610 to 1,220 meters); tops are 6,000 to 8,000 feet (1.8 to 2.4 km) MSL. Cumulus is the predominant cloud type, but some mid- and upper-level clouds may be present. Fog is rare but may occur in isolated inland valleys. Light haze is common but rarely restricts visibility to less than 5 miles. Sudden showers may reduce ceilings and visibilities to near zero for short periods. The freezing level is normally at about 15,000 feet (4.6 km) MSL; icing may be encountered in clouds, particularly convective types, above that level. Turbulence should also be expected in and near convective clouds.

WINDS. In January, upper winds remain easterly to 14,000 feet (4.3 km), backing through northerly at 15,000 feet (4.6 km), and to northwesterly or west-northwesterly through 50,000 feet (15.2 km). They return to easterly above 60,000 to 65,000 feet (18.3 to 19,8 km) MSL. Surface winds are easterly or east-northeasterly at 10 to 13 knots. Land and sea breezes are common. Locations on the western coast are more prone to local breezes because the easterly trades are often blocked by mountains. Locations on the southern coast get a southerly sea breeze during the day. Interior valleys and locations near mountains on the southern and western coasts may see land breezes at night, reinforced by cool air washing down the mountain slopes.

THUNDERSTORMS. Thunderstorms are infrequent during the dry season, occurring on only 1 day a month or less at most locations. Windward mountain stations may see more. Hail is highly unlikely at the surface but may occur in the higher mountains.

PRECIPITATION. In undisturbed air, the east-west orientation of the Cordillera Central ensures that, even though rainfall varies widely across the island, there are distinct regions of similarity. The easterly (and sometimes northeasterly) trades cause upslope precipitation along the northern and eastern parts of the island, where rainfall averages 3 to 5 inches (76 to 127 mm) a month. The southern coastal region, in subsiding air off the mountains, gets much less rain (1-3 inches/25-76 mm a month) . The western end of the island may or may not be affected by orographic precipitation, depending on whether flow is east or northeast. Mean rainfall there is 2 to 4 inches (51-102 mm) a month.

TEMPERATURES. The typical dry season day is warm and humid. Mean daily maximums run from the upper 70's to mid 80's°F (25 to 30°C). Mean daily minimums are from the upper 50's to the low 70's°F (15 to 23°C).

SEA SURFACE TEMPERATURES. January sea surface temperatures are near 80°F (27°C). The moderating effects of the water help maintain small annual temperature variation, particularly along coasts.

4.2 THE LESSER ANTILLES

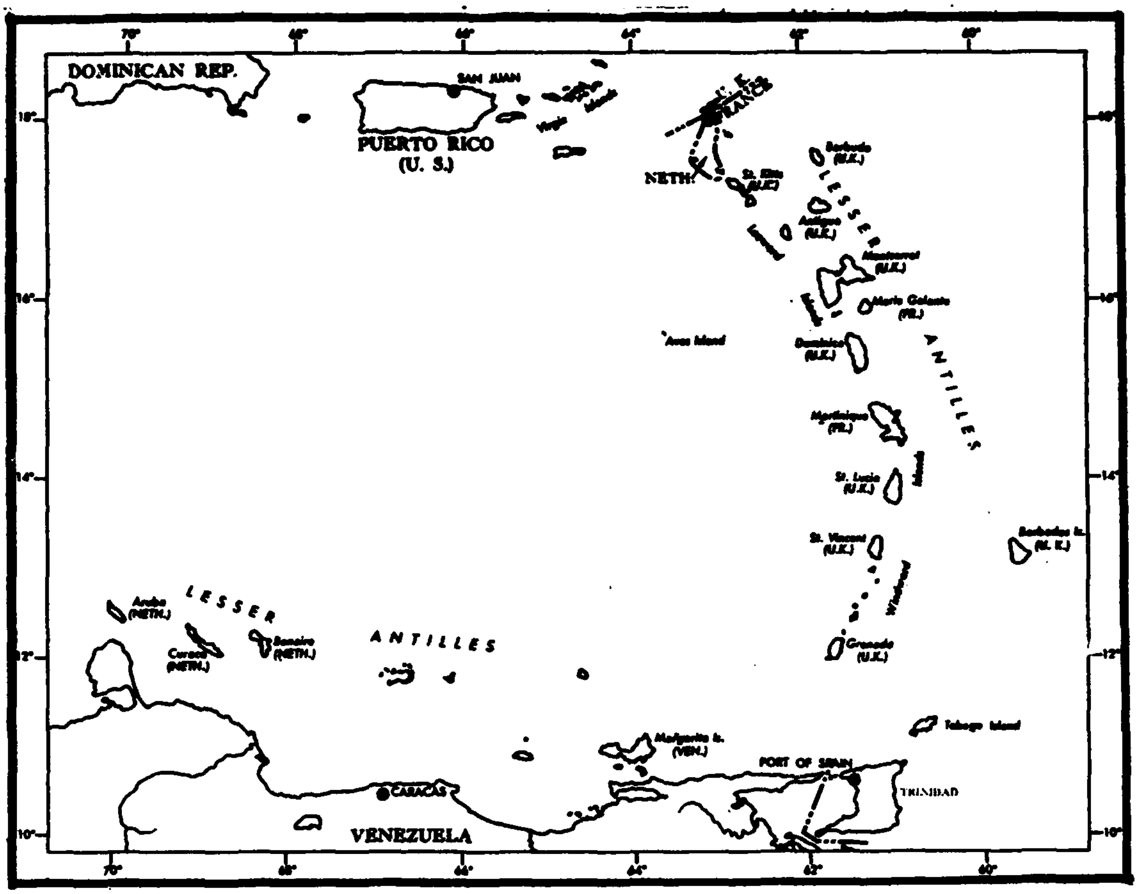


Figure 4-13. The Lesser Antilles. The Lesser Antilles form a gently curving chain of small island groups that swing down a north-south-west arc from Puerto Rico to Trinidad to Aruba. Most are volcanic in origin. From north to south, the Lesser Antilles comprise: (1) the Virgin Islands, (2) two large groups known as the Leeward and Windward Islands, (3) a smaller grouping made up of Barbados, Trinidad, and Tobago, and (4) a group referred to as the Southern Islands (or Netherlands Antilles) and composed of those islands just off the north coast of Venezuela.

A detailed discussion of the specific situation and location of the four major island groupings shown above follows in order. Then, on page 4-39, there are season-by-season discussions of Lesser Antilles climate and weather. With the exception of the southernmost groupings (the Southern Islands), most of the Lesser Antilles see two main seasons (dry and wet) with two brief transitions. In order of presentation, these are:

- *The dry season* (January-May)
- *The dry-wet transition* (mid May-early June)
- *The wet season* (June-December)
- *The wet-dry transition* (mid-December-Mid-January)

But in the Southern Islands (or Netherlands Antilles), the seasonal picture is slightly different; here, there is simply a dry season (February-June) and a wet season (July-January), with no discernible transition from one to the other. This regime is very similar to that of the Venezuelan Andes in Northern South America, which is discussed in Chapter 5. Because the climate and weather of the Southern Islands differ so much from the rest of the Lesser Antilles, they are discussed separately, beginning on page 4-47.

4.2.1 THE VIRGIN ISLANDS

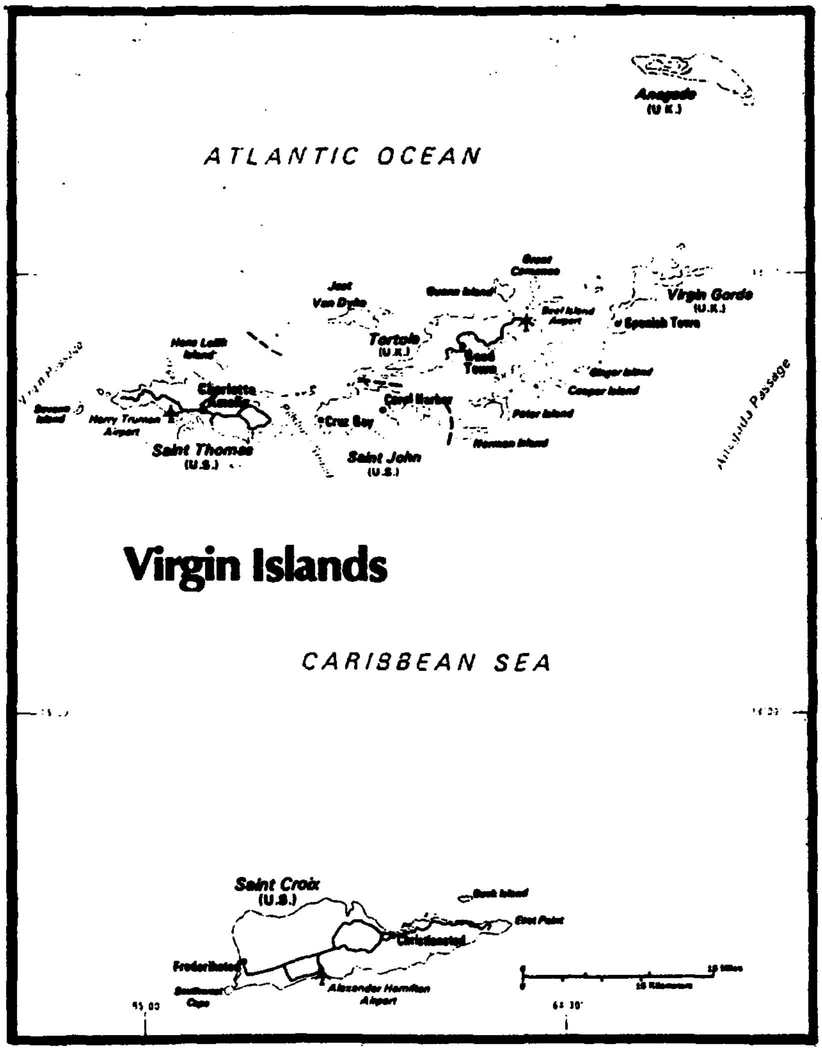


Figure 4-14. The Virgin Islands. The Virgin Islands, covering about 200 square miles and numbering about 80, lie about 60 miles (111 km) east of Puerto Rico in a scattered group divided administratively between the United States and the United Kingdom. Only the largest islands will be discussed.

THE UNITED STATES VIRGIN ISLANDS comprise Saint Thomas, Saint John, and Saint Croix, along with about 50 small islets. Together, they cover only 133 square miles. Saint Thomas (32 square miles) is 40 miles (64 km) east of Puerto Rico. Maximum elevation is 1,549 feet (472 meters). Saint John (19 square miles) is 4 miles (6 km) east of Saint Thomas. The highest point is 1,276 feet (389 meters). Saint Croix (82 square miles) is the largest, and lies 37 miles (59 km) due south of Saint John. The highest point is Mount Eagle (1,165 feet--355 meters), 7 miles (11 km) west of Christiansted.

THE BRITISH VIRGIN ISLANDS comprise about 28 small islands or islets, chief among which are Tortola, Virgin Gorda, Anegada, and Peter. Tortola is the largest (21 square miles); Mount Sage is its highest point at 1,710 feet (521 meters). Virgin Gorda is about 6 miles (11 km) east of Tortola. It covers 8 square miles, with its highest point at Two Peak, 1,381 feet (421 meters). Anegada is 12 miles (22 km) north of Virgin Gorda and is the northernmost island in the group. Maximum elevation is below 650 feet (200 meters). Peter Island is 4 miles (7 km) south of Tortola and has a maximum elevation of 440 feet (134 meters).

4.2.2 THE LEEWARD ISLANDS

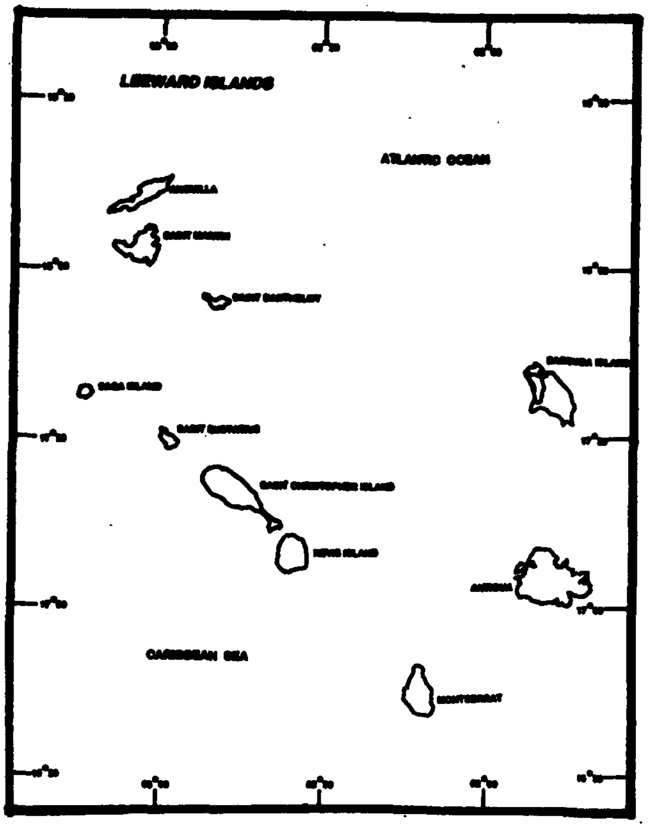


Figure 4-15. The Leeward Islands. The Leeward Islands form a loosely associated grouping that stretches nearly 250 miles (403 km) from Anguilla in the north to Guadalupe and Marie Galante in the south. From north to south, the Leeward Islands are:

ANGUILLA (UK). A low coral formation covering about 35 square miles. The highest point is 210 feet (64 meters) overlooking North Hill Village.

SAINT MARTIN (FR). About the size of Anguilla, but with higher elevations. The highest point (1,391 feet--424 meters) is 1 mile (2 km) west of Quartier d'Orleans. Salt ponds cover the low-lying portions.

SAINT BARTHELMY (FR). Only 9 square miles in area. The highest point is 922 feet (281 meters) 2 miles (4 km) southeast of Bay Saint Jean.

SABA ISLAND (UK-NE). Saba covers only about 5 square miles of land area, and is volcanic in origin. The highest point on the island is Mount Scenery, 2,828 feet (882 meters) above sea level.

SAINT EUSTATIUS (STATIA--NE). Seven square miles, also volcanic. Highest point is 1,978 feet (603 meters).

SAINT CHRISTOPHER ISLAND (ST KITTS). At 68 square miles, the largest of the St Eustatius-St Christopher-Nevis group. The highest point is Mount Misery (a dormant volcano cone) at 3,792 feet (1,156 meters). The small flat peninsula to the southeast is covered with salt ponds.

NEVIS ISLAND (50 square miles) is separated from the southeast peninsula of Saint Christopher by The Narrows, a channel 2 miles (4 km) wide and notorious for rough seas. Highest point is Nevis Peak at 3,232 feet (958 meters). The island is called *Nevis* because of the clouds that shroud this peak almost continuously.

BARBUDA ISLAND, a dependency of Antigua, breaks from the chain to lie about 42 miles (78 km) east-northeast of St Christopher/Nevis. Area is 62 square miles and of coral formation. Highest point is 144 feet (44 meters) in the north part of the island. Barbuda is dry and surrounded by coral reefs.

ANTIGUA lies about 25 miles (46 km) south of Barbuda and covers 108 square miles. There are several disorganized groups of small hills. The coastline is indented with alternating bays and rocky headlands. There is a harbor at St John's. Highest point is 1,319 feet (402 meters) 2 miles (3 meters) west of Falmouth on the south side of the island.

REDONDA is a small, uninhabited and rocky islet, maximum elevation 1,000 feet (305 meters). It is a major source of phosphate.

MONTSERRAT (UK) is 22 miles (41 km) southwest of Antigua with 40 square miles. It is formed of two volcanic mountain ranges separated by a saddle behind the town and port of Plymouth. The southern range rises to 3,000 feet (914 meters) in the Soufriere Hills.

GUADELOUPE (FR) encompasses 680 square miles. It comprises what actually amounts to two islands separated by a narrow strait (Riviere Salee, or Salt River), which is bridged. The western portion of the double island is known as Basse-Terre (named "low land" because of its lower latitude--not because of its elevation). The eastern portion is called Grand Terre, or "high land", for the same reason. There are rugged volcanic mountains on Basse-Terre rising to 4,813 feet (1,467 meters) at La Soufriere, an active volcano. The entire area is characterized by fumaroles, cinder holes, and sulphurous springs. The highest point on Grand Terre is only 443 feet (135 meters).

LA DESIRADE (FR) is 5 miles (9 km) due east of Grand Terre. Its highest point (906 feet--276 meters) is at Grand Montagnes.

MARIE GALANTE is 16 miles (30 km) east of the southern tip of Basse-Terre and covers 58 square miles. The highest point is 669 feet (204 meters).

LES SAINTES is a four-island group (Terre de Bas, Islet Cabrit, Terre-de-Haut, and Grand Islet) 7 miles (13 km) south of Basse-Terre. The highest point is on Terre-de-Haut at 1,050 feet (320 meters).

4.2.3 THE WINDWARD ISLANDS

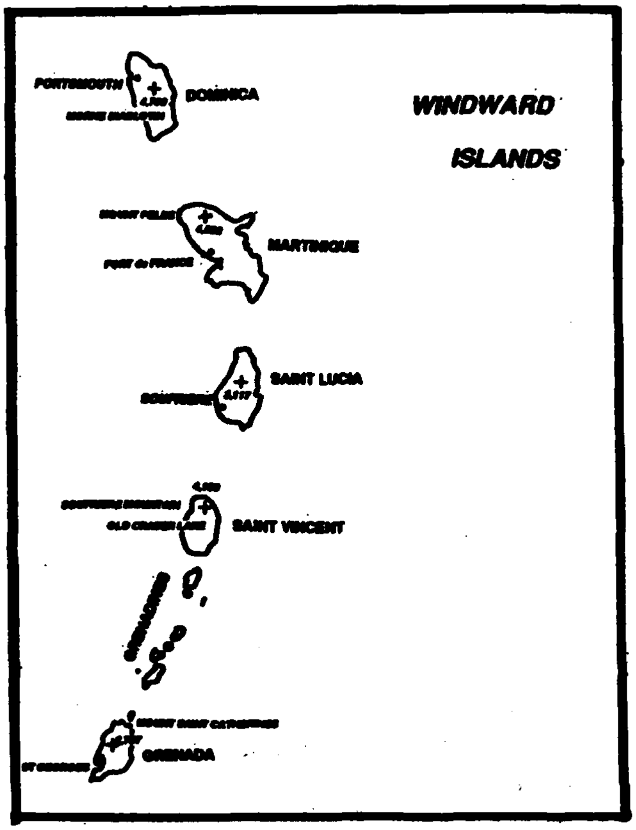


Figure 4-16. The Windward Islands. The Windward Islands, all volcanically formed, are still marked by active vulcanism. They form a curving chain that runs from Dominica in the north to Grenada in the south. The principal islands of the Windward Islands are:

DOMINICA is 17 miles (31 km) southwest of Marie Galante. It is 30 miles (56 km) long by 12 miles (22 km) wide and covers 305 square miles. Like the other islands in this group, volcanic activity is still present, with numerous fumaroles, cinder holes, and hot sulphur springs. The highest peak (Morne Diablotin) rises to 4,700 feet (1,433 meters), the highest point in the Lesser Antilles. Most of Dominica, except for a narrow coastline, is over 1,000 feet (305 meters). Many of the mountainous areas are covered with hardwood forests. Portsmouth is on the northwest coast.

MARTINIQUE is 22 miles (41 km) south-southeast of Dominica and covers 425 sq miles. Mount Pelee, at 4,583 feet (1,397 meters) erupted in 1902 and totally destroyed the city of St Pierre on the northwest side of the island. Like Dominica, vulcanism on Martinique is still active. A 50-mile-square plain lies across the center of the island. Most of Martinique is above 1,500 feet (457 meters). Fort de France is halfway down the southwest coast.

SAINT LUCIA is 18 miles (23 km) south of Martinique with similar topography. It covers 238 squares miles. The highest point is Canaries Mountain near Soufriere at 3,117 feet (950 meters) in the south central part of the island.

SAINT VINCENT covers 150 sq miles. Topography is much the same as the other islands in the group--mostly mountainous, volcanic, narrow coastlines. The highest point on Saint Vincent is Soufriere Mountain at 4,100 feet (1,250 meters). A crater lake just south of this feature is 2,000 feet (610 meters) below the precipitous rim which stands at 3,500 feet (1,067 meters).

THE GRENADINES, a miniature island chain that stretches for about 60 miles (111 km) from St Vincent to Grenada, includes Bequia, Isle Quatre, Baliceaux Island, Mustique, Canouan, Mayreau, Union Island, Carriacou, and Ronde Island. The Martinique Channel runs between Union Island and Carriacou.

GRENADA, the smallest island in the group, is 90 miles (167 km) north of Trinidad and covers 120 square miles. The highest point is Mount Saint Catherines at 2,757 feet (840 meters). St Georges is on the southeast coast.

4.2.4 BARBADOS, TRINIDAD, AND TOBAGO

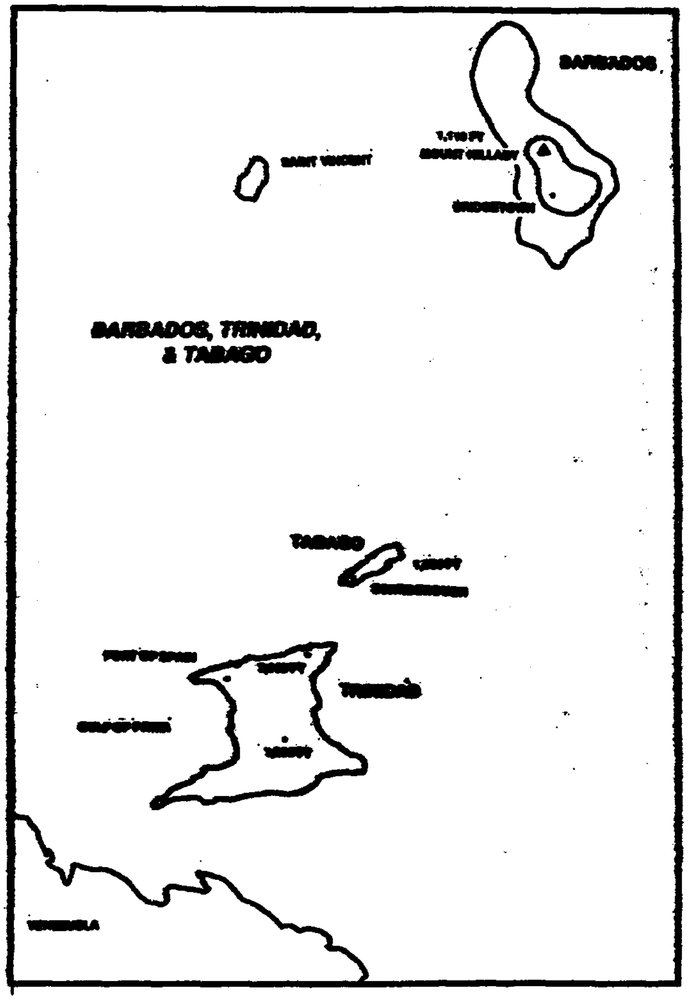


Figure 4-17. Barbados, Trinidad, and Tobago. It is convenient to group these three islands because of their similar situation and relief. Note that Barbados, well to the northeast of Trinidad, is detached from the gentle curve formed by the other islands in the chain.

BARBADOS is about 90 miles (167 km) east of Saint Vincent. This coral island covers 166 square miles and is relatively flat. The highest point is Mount Hillaby in the north central part of the island at 1,110 feet (338 meters). Bridgetown is on the southwest coast.

TOBAGO is 32 miles (59 meters) long, and is 29 miles (54 km) north-northwest of Trinidad. It covers 116 square miles. The highest point is in the central portion of the island at 1,950 feet (594 meters). The southwestern tip is flat. Scarborough is on the southeast coast.

TRINIDAD, only a few miles off the coast of Venezuela, is geologically a part of that country. With 1,864 square miles, Trinidad is nearly square. Two peninsulas extend westward from the northwest and southwest corners to enclose the Gulf of Paria. The northern peninsula and adjacent islands are separated by Boca Grande. The island is mostly plain, with an east-west range of hills along the northern coast that reach to 3,085 feet (940 meters). A smaller range of hills in the center of the island reaches only to 1,009 feet (308 meters). A few smaller hillocks dot the southern coast. There are swampy regions on the east and west sides of the island. Port of Spain is on the sheltered side of the northwest coast.

GENERAL WEATHER. The Lesser Antilles island grouping (as described on the foregoing pages) is dominated by the northeasterly trade winds located on the southern flank of the Azores High. Day-to-day weather in the winter, or dry season, varies little under the influence of the trade wind inversion, which has a mean dry season height of 7,500 feet (2.3 km) MSL. The inversion is strongest now because of the Azores High, which is at its southernmost position (30° N, 35° W) through April. Ex-continental migratory high pressure centers originating in the United States occasionally move across the western Atlantic to reinforce this low-level stability. These highs may follow a weakened front or may arrive long after the southern part of an old North American frontal zone has dissipated. The northern part of the Leeward Islands is influenced much more by these highs than are the Southern Islands (or Netherlands Antilles), which see. Although forced lifting of the trade winds over mountains may induce convection, only a few islands in this group have the terrain necessary for significant orographic precipitation.

Although modified polar outbreaks are rare, they occasionally reach into the Lesser Antilles. By the time they move this far south, however, most frontal characteristics have disappeared, leaving only a wind shift boundary or shear line to produce showers and thunderstorms. Polar surges are usually not observed after the end of April.

SKY COVER. Dry season sky cover is between 3 and 5 tenths, mainly cumulus or stratocumulus with some cirrus. In the northern part of the Lesser Antilles, weak polar outbreaks may increase cloud cover to 6-9 tenths for several days. Cloud bases are normally 2,000 to 4,000 feet (610 to 1,220 meters), but are considerably lower for very brief periods during sudden, heavy showers. As shown in Figure 4-18, diurnal cloud cover variation is normally small. This is true at locations with frequent cloud cover in the dry season (such as Dominica) as well as on those islands with less low cloud cover (such as Grenada). The only exception is in the northern coastal mountains of Trinidad, where there is more afternoon convective cloud cover; ceilings here are between 2,000 and 3,000 feet (610 to 915 meters) 20-30% of the time between noon local and sunset. In the modified polar air following an old front, the Leeward Islands may see several days with convective cloud cover in the afternoon. Once the trade wind inversion is reestablished, cloud tops are normally capped at 6,000 to 8,000 feet (1.83 to 2.4 km).

Ceilings and visibilities are below 3,000/3 no more than 10-15% of the time at most locations, and below 1,000/2 up to 4% of the time. Visibility is usually 7 miles or better. Fog is rare but may occur on larger islands in low lying, marshy areas on calm nights. Light haze is often observed from the surface to the trade wind inversion; on rare occasions it may reduce visibility to 5 miles. The freezing level is usually near 15,000 feet (4.6 km). Although not a problem below 15,000 feet, moderate mixed icing (and moderate turbulence) can occur above the freezing level in towering cumulus and cumulonimbus.

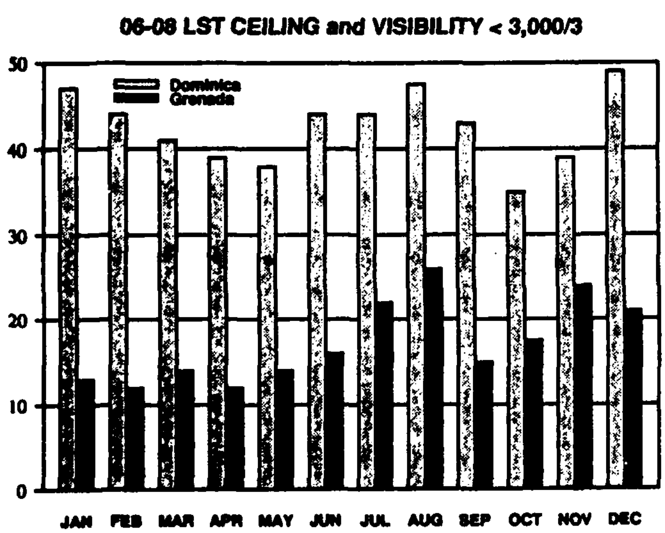


Figure 4-18a. Ceiling/ Visibility < 3,000/3, 06-08 LST, Dominica vs. Grenada.

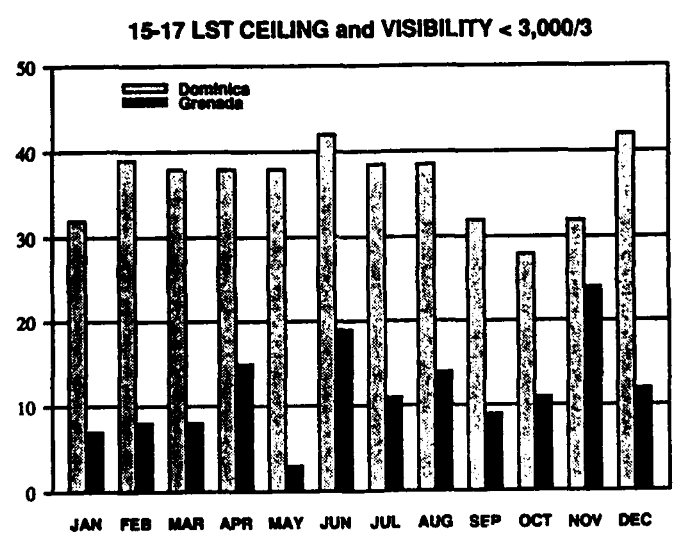


Figure 4-18b. Ceiling/ Visibility < 3,000/3, 15-17 LST, Dominica vs. Grenada.

WINDS. Easterly trade winds prevail over most of the islands at 10-14 knots, but speeds on Trinidad and Tobago (and in the Grenadines) are only 6-9 knots. Direction rarely varies from easterly by more than 20 degrees throughout the Leeward Islands, but winds over the lower Windwards, Trinidad, and Tobago are more east-northeasterly.

Many islands in the Lesser Antilles are too small to have perceptible land or sea breezes; on some of the larger islands, the trade winds are strong enough to mask any effects a land or sea breeze might have. The islands of St. Christopher, Guadeloupe, Dominica, Martinique, and Trinidad, however, are large enough, with the right kind of terrain, to produce both land and sea breezes (especially sea breezes) when the trade winds are light.

Over the Leeward Islands in January, easterly winds persist to 13,000 feet (4.0 km), switching back to northerly or northwesterly at 21,000 feet (6.4 km), then becoming northwesterly through 50,000 feet (15.2 km). Over Trinidad, winds are westerly from 33,000 to 43,000 feet (10.0 to 13.1 km), returning to northwesterly at 50,000 feet (15.2 km). Winds over the entire Leeward Island region return to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km). Figure 4-19a shows low-level (15,000 feet and below) mean wind directions in the southern region of the Lesser Antilles. Figure 4-19b shows mean wind directions for 20,000, 25,000, and 30,000 feet.

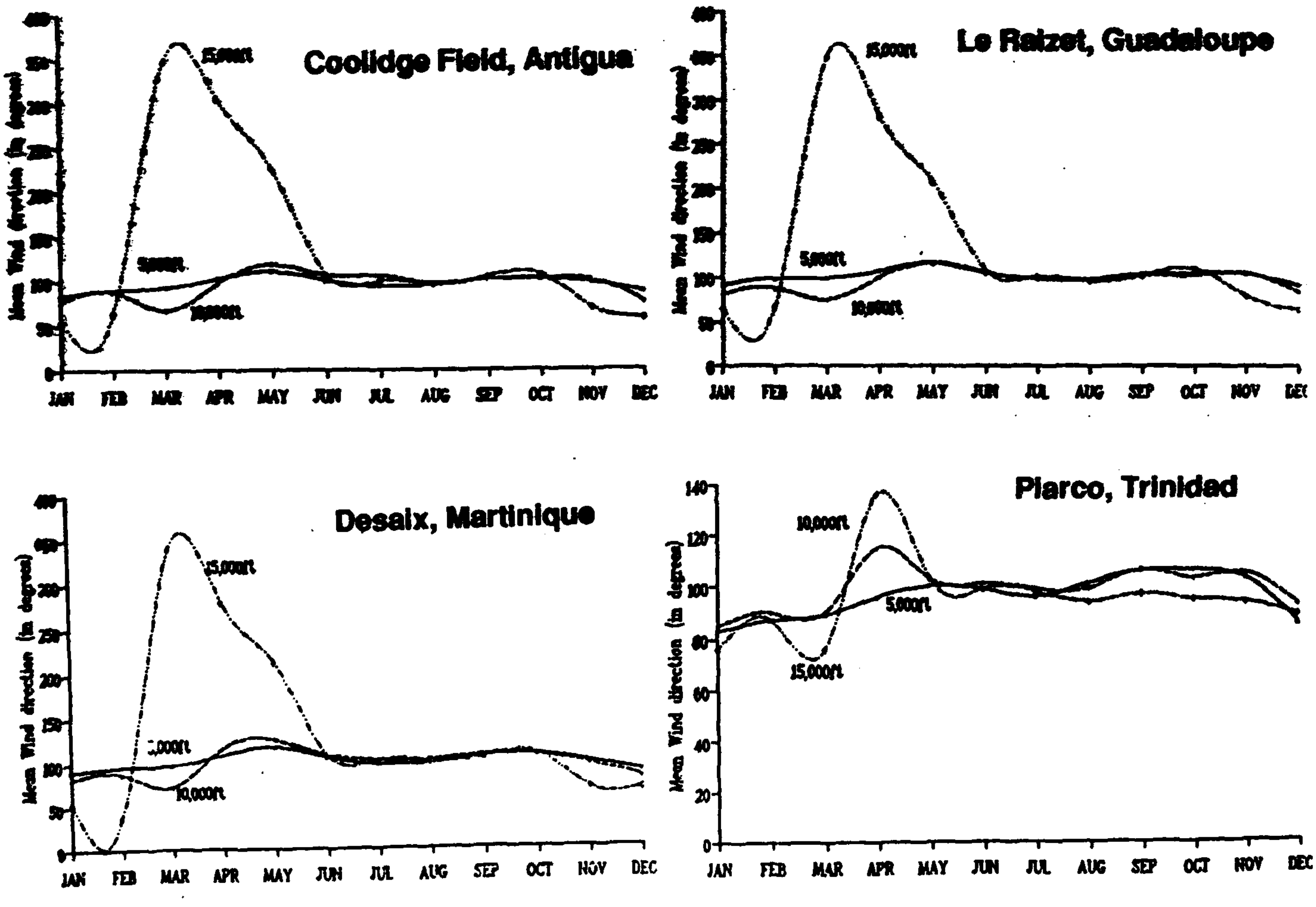


Figure 4-19a. Mean Low-Level (5, 10, 15K) Wind Directions for Selected Stations in the Lesser Antilles.

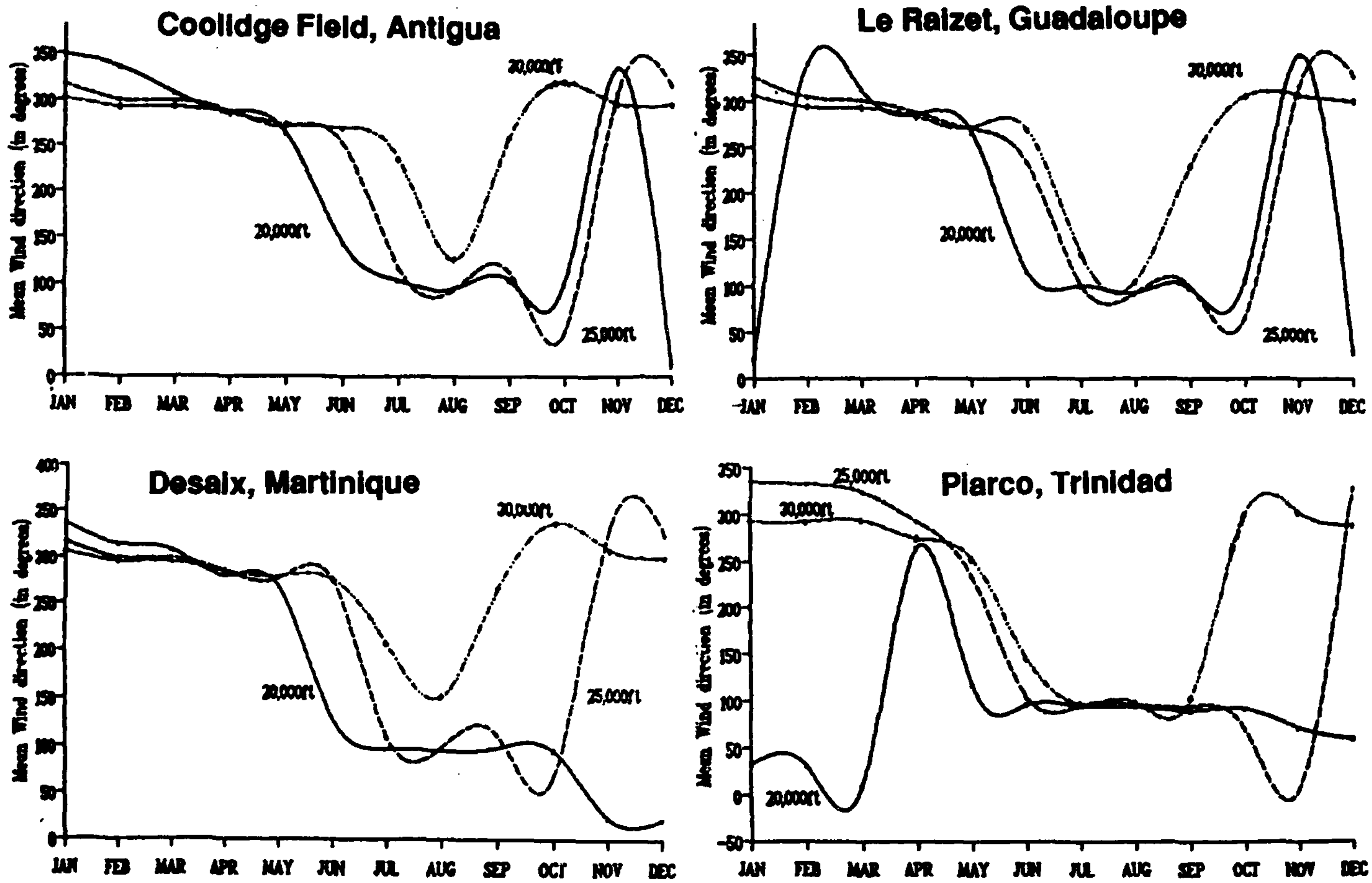


Figure 4-19b. Mean Upper-Level (20, 25, 30K) Wind Directions for Selected Stations in the Lesser Antilles.

THUNDERSTORMS are infrequent during the dry season, usually occurring on 1 day or less a month at most locations. Windward slopes of mountainous islands see a few more thunderstorms due to forced upslope lifting of the moisture-laden trade wind flow. Hail is very rare, but may occur at elevations above 4,000 feet.

PRECIPITATION. Rain usually falls as sudden showers that can reduce ceiling and visibility for brief periods. The smaller islands average 2 to 4 inches (51 to 102 mm) of rain during the dry season; the larger islands get more due to interaction of the easterly trade winds with terrain features; for example, the higher terrain of several of the Windward Islands (Saint Vincent and Saint Lucia) results in 4 to 6 inches (102 to 153 mm) there. Although these mountainous islands may not see significantly more cloud cover than their flatter neighbors, cumulus and stratocumulus tops are high enough to cause more rainshowers. A pronounced rain shadow is evident along the leeward sides of the larger islands.

TEMPERATURES. Mean daily maximum temperatures are 82 to 87°F (28 to 30°C). Mean daily minimum range is 68 to 73°F (20 to 22°C). Higher elevations may be as much as 10°F (6°C) lower. Figure 4-20 shows the relatively constant mean temperatures at two representative locations in the Lesser Antilles.

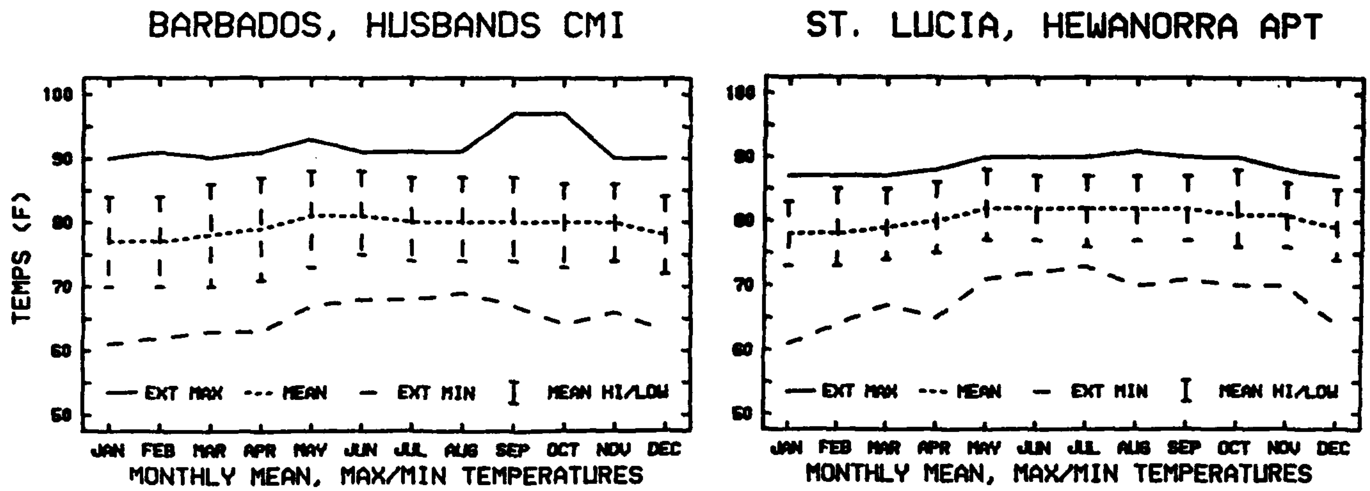


Figure 4-20. Monthly Mean and Maximum/Minimum Temperatures: Husbands CMI, Barbados, and Hewanorra Airport, St Lucia.

SEA SURFACE TEMPERATURES. Mean sea surface temperatures in February are 79°F (26°C), about 1°F (.6°C) warmer than the mean air temperature. Mean air and sea surface temperatures are equal at 79°F (26°C) in the Windward Islands, Trinidad, and Tobago. The result is a very small annual or diurnal temperature range.

GENERAL WEATHER. Large-scale flow becomes more easterly than northeasterly. The trade wind inversion begins to weaken and rise as the Azores High moves north. As upper-level subsidence lessens, the unstable lower layers deepen, allowing convection and shower activity to become more widespread.

SKY COVER. Cloud cover increases slightly; ceilings are below 3,000/3 between 15 and 20% of the time. But on the more mountainous islands (such as Saint Lucia and Trinidad), afternoon ceilings are below 3,000/3 from 25 to 30% of the time. In the weakened trade wind inversion, tops can now exceed 10,000 feet (3.1 km).

WINDS. Winds remain easterly at 5-10 knots below 20,000 feet (6.1 km), northwesterly at 20-30 knots above.

THUNDERSTORMS. The mean number of thunderstorm days remains low, with only 1-2 a month.

PRECIPITATION. Increased low-level instability shows up in the increased monthly rainfall. There is very little island-to-island variation in rainfall amount--most stations average between 3 and 5 inches (76 to 127 mm) a month.

TEMPERATURES. Mean highs are in the low- to mid-80s°F (28 to 30°C). Mean lows are in the mid- to upper-70s°F (24 to 26°C).

GENERAL WEATHER. By September, the moist easterly trades extend upward to more than 25,000 feet (7.6 km) over most of the Lesser Antilles, and up to 34,000 feet (10.4 km) over Trinidad. The Atlantic Ocean east of the islands is an especially active region for tropical storm development; although no island in the Lesser Antilles is immune to tropical storms, Trinidad and Tobago are much less likely to be affected by them. During the southern hemisphere winter (northern hemisphere summer), southern hemisphere polar surges, which can occur well into October, may push the Monsoon Trough northward into the Windward Islands. This northward oscillation of the Monsoon Trough may last for several days, bringing well developed mid- and upper-level clouds, along with embedded showers and thunderstorms, northward into the islands. This phenomenon, linked to the severity of the southern hemisphere winter, varies in frequency from year to year. The influence of the Monsoon Trough is greatest in southern portions of the Lesser Antilles. For a more detailed discussion of northern hemisphere polar surges, see Chapters 2 and 5.

SKY COVER. Cloud cover is usually 5 to 7 tenths of cumulus and towering cumulus; this compares with only 3-5 tenths coverage during the dry season. Afternoons are cloudiest. Bases average 2,000 to 4,000 feet (610 to 1,220 meters) but may lower to near the surface during heavy showers and thunderstorms. Towering cumulus tops may reach to 15,000 feet; cumulonimbus tops may exceed 40,000 feet (12.2 km). Cumulonimbus cirrus anvils can be carried a considerable distance by the strong upper-level easterlies. Daily cloud cover is greatly influenced by the presence of the Monsoon Trough. Although most locations see a general increase in cloud cover during summer months, it doesn't happen everywhere. Diurnal variation is greatest in the wet season, especially on the larger islands of the Lesser Antilles. The general instability in the lower layers during the wet season results in the nearly continuous presence of trade wind cumulus. The frequency of ceiling/visibility below 3,000/3 increases to 25-30% at most locations, but the frequency of occurrence below 1,000/2 (less than 4%) remains about the same as during the dry season. Windward mountain slopes (such as on Guadeloupe, St. Christopher, and Dominica) may have significantly higher frequencies of low ceilings and visibilities. The passage of tropical disturbances may bring several days of showers and thunderstorms. Fog is rare, but light haze is often present. Dry season haze may extend to the trade wind inversion, but it rarely restricts visibility to less than 5 miles. Moderate mixed icing may occur in towering cumulus and cumulonimbus above the freezing level. Moderate to severe turbulence may accompany towering cumulus and cumulonibus at all levels.

WINDS. The easterly trade winds continue to prevail, with mean speeds from 7 to 12 knots. But whenever the Monsoon Trough moves north into the Lesser Antilles, low-level winds change from east to southwest. Depending on the strength of these southern hemisphere polar surges, winds can gust to 15-20 knots. As the Trough sags back southward, wind speeds decrease and easterly flow is reestablished. The only gale force winds (speeds greater than 28 knots) occur with tropical disturbances or easterly waves; directional shear near the center of these disturbances can be significant. On most islands (especially the smaller ones), the trade winds are strong enough to mask any land/sea breeze effect. But when the tradewinds are calm, the larger islands will see land breezes at night and sea breezes during the day.

As was shown in Figures 4-19a and b, large-scale wet season flow over most of the Lesser Antilles remains easterly up to 30,000 feet (9.2 km), veering to westerly at 30,000 to 33,000 feet (9.2 to 10.1 km) and remaining so to 50,000 feet (15.2 km). Over Trinidad, winds remain easterly to 34,000 feet (10.4 km), backing sharply to northwesterly at 36,000 feet (11.0 km), then moving to west-northwesterly at 50,000 feet (15.2 km). Winds return to easterly over the entire area above 60,000 feet (18.3 km).

TROPICAL DISTURBANCES. The storm season runs from June through November, with the highest frequency of occurrence in August, September, and October; only 2% of the storms that affect the Lesser Antilles occur in November. Normally, tropical disturbances are not yet fully developed as they pass the Lesser Antilles; in any case, none of the islands in the Lesser Antilles are large enough to affect the strength of any disturbance that may cross them.

Easterly waves, which bring showers, thunderstorms, and torrential rains, vary in frequency from year to year. During those years that the Monsoon Trough moves into the southern Caribbean frequently, easterly waves are deflected North and rarely seen in and south of the Windward Islands. But during those years that the Monsoon Trough stays south of the Caribbean, easterly waves may be expected to cross the Lesser Antilles region every 5 to 7 days through early November.

THUNDERSTORMS. Days with thunderstorms increase through the wet season to average 5-7 a month. The more mountainous of the islands (because of orographic lift) and those farther south (because of proximity to the Monsoon Trough) can expect as many as 10-15 thunderstorm days a month; see Figure 4-21. Most thunderstorms occur in the afternoon.

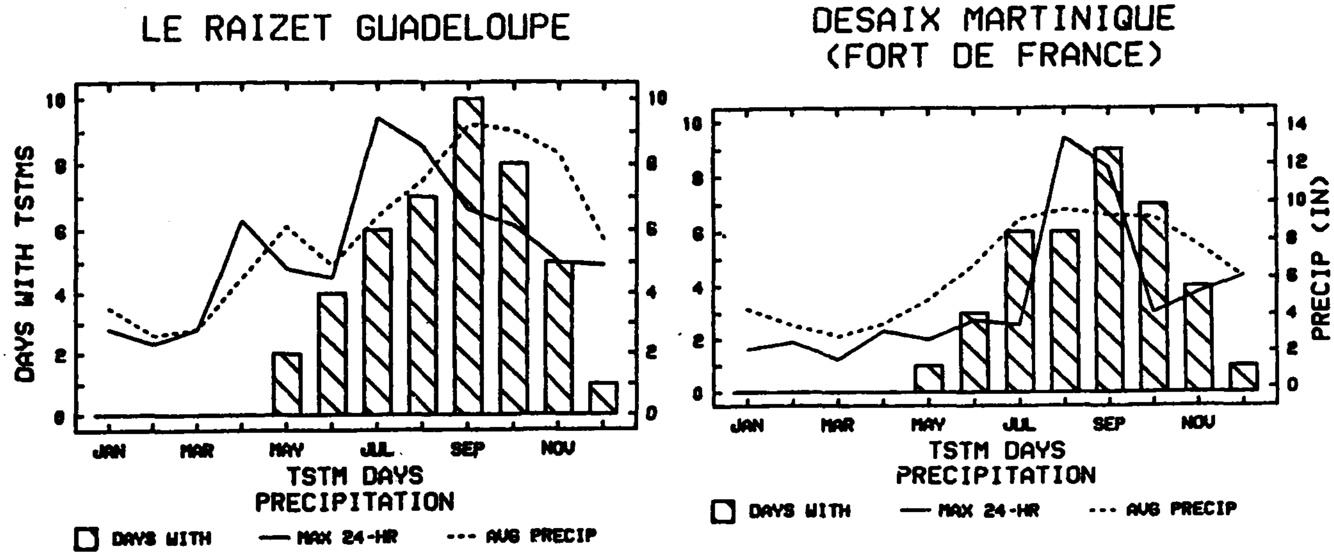


Figure 4-21. Days with Thunderstorm and Precipitation Amounts: Le Raizet, Guadelope; and Desaix, Martinique.

PRECIPITATION. Wet season precipitation is almost a daily occurrence in the Lesser Antilles; rain falls on 20-25 days a month, mainly as showers or thundershowers of short duration that may reduce ceilings and visibilities to near zero for short periods (usually less than half an hour). Mean monthly rainfall increases from north to south. Most of the Leeward Islands average 6 to 8 inches (152 to 203 mm) a month, but the Windward Islands, along with Trinidad and Tobago, average 8 to 10 inches (203 to 254 mm). Only a few islands of the Lesser Antilles have the topography necessary for an orographic effect on precipitation. They are Montserrat and Guadeloupe in the Leeward Islands; Martinique, Saint Lucia, Saint Vincent, and Grenada in the Windward Islands; and Trinidad. On these islands, windward slopes get more rain due to orographic lifting, while leeward slopes are shielded.

TEMPERATURES. Mean daily maximum temperatures are 85 to 90°F (29 to 32°C). Mean daily minimums are from 70 to 78°F (21 to 25°C). Temperatures may be 10°F (6°C) lower in the highest mountains.

SEA SURFACE TEMPERATURES. Mean July sea surface and air temperatures are about equal at 82°F (28°C) in most locations except at Trinidad, where sea surface temperatures are 80 to 81°F (27°C).

GENERAL WEATHER. As the Azores High begins to move south to its dry season location (30° N, 35° W), the trade wind inversion strengthens and lowers. Tropical disturbances, easterly waves, and the Monsoon Trough can still influence Lesser Antilles weather, especially early in the transition. North American polar air masses and associated post-frontal high pressure systems begin to reappear.

SKY COVER. Mean cloud cover decreases to 4-5 tenths, but southern portions of the islands retain wet season cloud cover (5-7 tenths) for a little longer than in the north. Tradewind cumulus and stratocumulus remain the predominant cloud types, with bases between 2,000 and 3,000 feet (610 and 915 meters). Average cloud tops decrease with the lowering trade wind inversion, moving to dry season heights of 6,000 to 8,000 feet (1.8 to 2.4 km).

WINDS. Low-level flow is still easterly at 5-10 knots. The frequency of gusty winds decreases as tropical disturbances become less frequent.

THUNDERSTORMS. Thunderstorm days average 3-4 a month throughout the Lesser Antilles, but frequency drop as the trade wind inversion lowers to limit convection. The decreasing frequency of tropical disturbances results in fewer thunderstorms moving into the region.

PRECIPITATION averages between 3 and 5 inches (76 to 127 mm) throughout the islands, but some variation can be expected early in the season in mountainous areas, especially on Saint Lucia, Saint Vincent, and Trinidad, where monthly averages are nearly an inch more.

TEMPERATURES. Average highs are in the low to mid 80s°F (28 to 30°C). Average lows are in the low to mid 70s°F (22 to 24°C). Temperatures can be 10 to 15°F (6-8°C) lower in the mountains or following passage of a modified North American polar front.

4.2.5 THE SOUTHERN ISLANDS

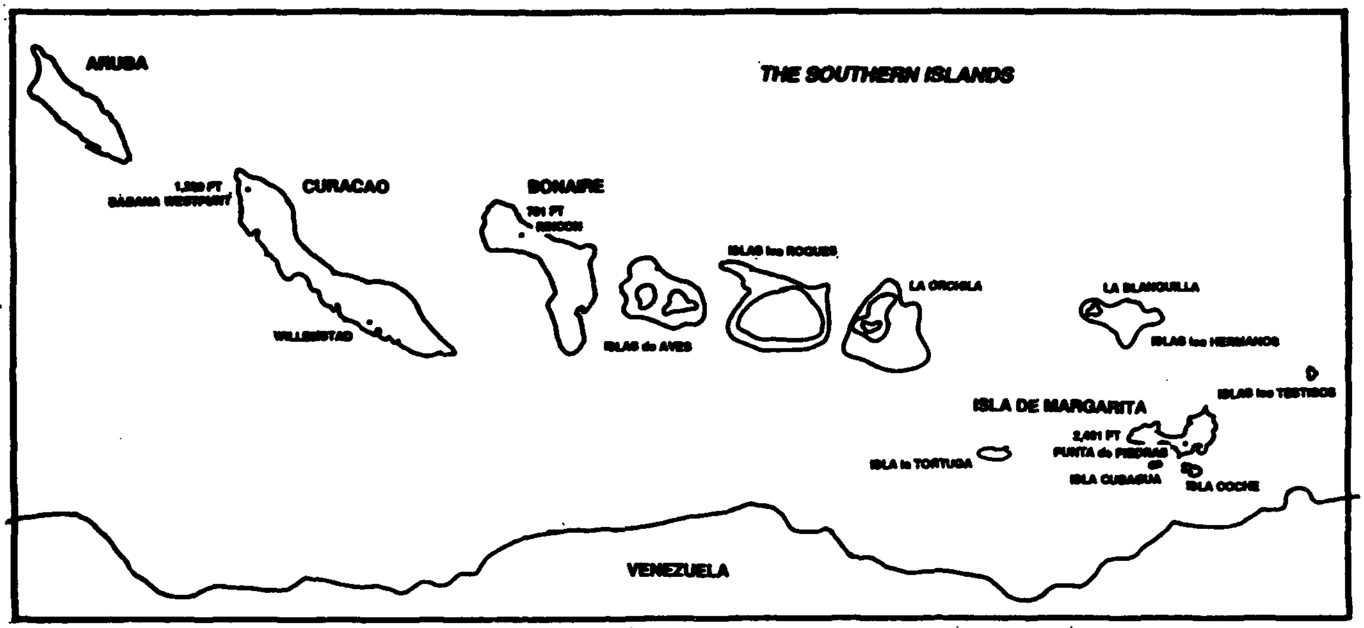


Figure 4-22. The Southern Islands. The grouping we shall call the Southern Islands is a chain of small, low-lyi g islands along the north coast of Venezuela. These islands form a 378-mile (700-km) string from Aruba in the wes: to Isla de Margarita in the east. Aruba, Bonaire, and Curacao, the largest of the Netherlands Antilles, are often c lled the "ABC" islands. The Southern Islands have two main seasons, but without the recognizable transiti n periods found in the rest of the Lesser Antilles to the north. These are: the dry season (February-June), and the wet season (July-January). From west to east, the Southern Islands are:

ARUBA is 19 miles (35 km) long by 5 miles (9 km) wide and covers ( ) square miles. Aruba is generally flat, dry, and barren, r sing from sea level to 617 feet (188 meters).

CURACAO is 36 miles (67 km) by 8 miles (9 km) and covers 182 square miles. Also flat, dry, and barren, its highest point is 1,220 feet (372 meters) above sea level near the northwest tip at Sabana Westpunt. Willemstad is halfway down the southern coast.

BONAIRE is 30 miles (51 km) east of Curacao and has 111 square miles of land. The highest point is 791 feet (241 meters) near Rincon. The southern tip is marshland.

MINOR ISLANDS/ISLETS that lie between Bonaire and Isla de Margarita are, from west to east: Islas de Aves, Islas los Roques, La Orchila, Isla la Tortuga, La Blanquilla, and Islas los Hermanos. The Islas los Testigos, a very small islet grouping, lies about 50 miles northeast of Margarita. The Isla Cubagua and Isla Coche lie between Margarita and the Venezuelan coast.

ISLA DE MARGARITA (Venezuela) is made up of two mountains separated by a flat coastal plain. The westernmost mountain is called Punta de Piedras and reaches to 2,461 feet (750 meters). Two peaks on the main (eastern) part of the mountain reach 2,297 feet (700 meters) and 2,953 feet (902 meters).

GENERAL WEATHER. There are no real season-to-season "transitions" here; weather in the Southern Islands is remarkably constant the year around. When certain weather phenomena (the Monsoon Trough, easterly waves, tropical disturbances) do influence the Southern Islands, they typically do so between July and January. Late in the "dry" season (and also during the "wet" season), the islands see an increase in the frequency of scattered light rainshowers that raises mean monthly rainfall amounts slightly. Rare events notwithstanding, the dry season pattern here is a steady progression of hot and humid days with afternoon trade wind cumulus.

The Southern Islands are dominated by the easterly trade winds set up by the Azores High. These easterlies generally extend to 17,000 feet (5.2 km) in February. The trade wind inversion has a mean height of roughly 8,500 feet (2.6 km). Very little variation in weather occurs in the Southern Islands except during the arrival of a rare, unusually strong cold air surge. Such surges cause brief, and extremely rare, heavy rainfall. The heaviest showers are associated with the immediate passage of the associated polar upper-air trough. Although all frontal characteristics are lost during such long-distance penetrations, discontinuities in the wind field can be noted.

The dry season here is extremely dry. Although the exact causes for this are still not entirely understood, one factor is the strong low-level divergence near the Venezuelan coast; winds here become anticyclonic because of the orientation of the Venezuelan Andes and Lake Maricaibo. Mountainous terrain curves southwestward around the eastern shore of Lake Maricaibo and into Colombia. By late May and June, southerly flow off the Venezuelan Andes may reach the islands as a result of a strong southern hemisphere cold surge descending the northern--leeward--slopes. Lower sea surface temperatures (lower when compared to other Caribbean Sea areas) serve to stabilize the lower levels of the atmosphere. Another factor is the considerable upper-level convergence along the entire coastal region. Southwesterly flow moves out of South America into the southern Caribbean Sea as the subtropical ridge straddles the equator; northwesterly flow sets up over North America and the northern Caribbean Sea.

SKY COVER is 3 to 5 tenths cumulus or stratocumulus, with some cirrus. Cloud bases are 2,000 to 3,000 feet (610 to 915 meters), but infrequently constitute a ceiling. Cloud tops are 6,000 to 8,000 feet (1.8 to 2.4 km). Ceilings and visibilities are below 3,000/3 less than 10% of the time and below 1,000/2 only 2% of the time or less. Afternoons are cloudiest. Aruba (see Figure 4-23) is representative of most stations in the region. Surface heating produces cumulus buildups over land in the afternoon, but little or no cloud forms over water. The reverse occurs at night. Visibility is usually 7 miles or better. Fog is rare. Light haze is often observed from the surface up to the trade wind inversion; it may, on rare occasions, reduce visibility to 5 miles. Icing is extremely rare; the freezing level is near 15,000 feet (4.6 km).

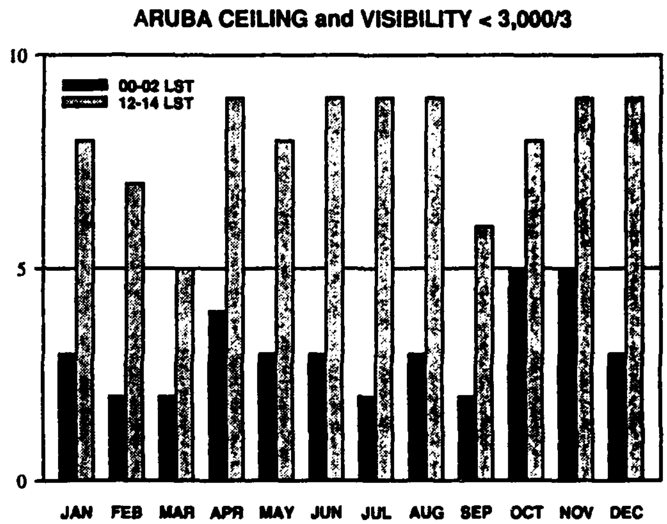


Figure 4-23. Percent Frequency of Ceiling/Visibility below 3,000/3 at Aruba.

WINDS. The easterly trade winds are surprisingly strong, with mean speeds of 15 to 17 knots, because: (1) the pressure gradient of the Azores High is strongest here during the dry season, and (2) the pressure gradient is strengthened by significant differential heating between the large South American land mass and the ocean. The strong winds here may also have a southeasterly component due to the orientation of the nearby Venezuelan coastline. The islands in this group are too small for perceptible land/sea breezes; the strong prevailing easterlies mask any such effects. When the trades are weak, however, some islands (especially Aruba) may feel a late-night land breeze off the Venezuelan coast, supported by the mountain winds of the nearby Venezuelan Andes. Wind directions change from east to southwest, but speeds remain relatively low at 5-10 knots.

February winds are easterly to 17,000 feet (5.2 km), as shown in Figure 4-24a. From 20,000 to 30,000 feet (6.7-9.1 km), they back through northerly to westerly, as shown in Figure 4-24b. From 30,000 through 50,000 feet (9.1-15.2 km), winds remain westerly. Above 60,000 feet (18.3 km), they return to easterly.

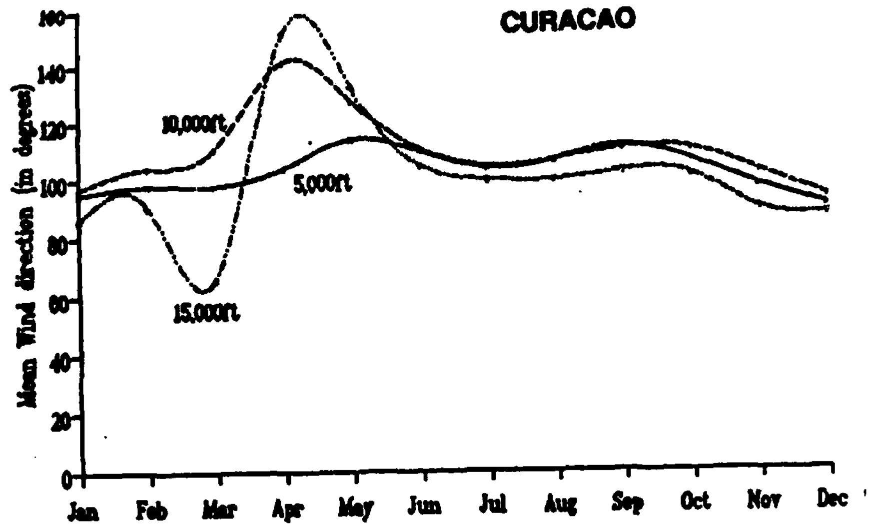


Figure 4-24a. Mean Low-Level (5, 10, 15K) Winds at Curacao.

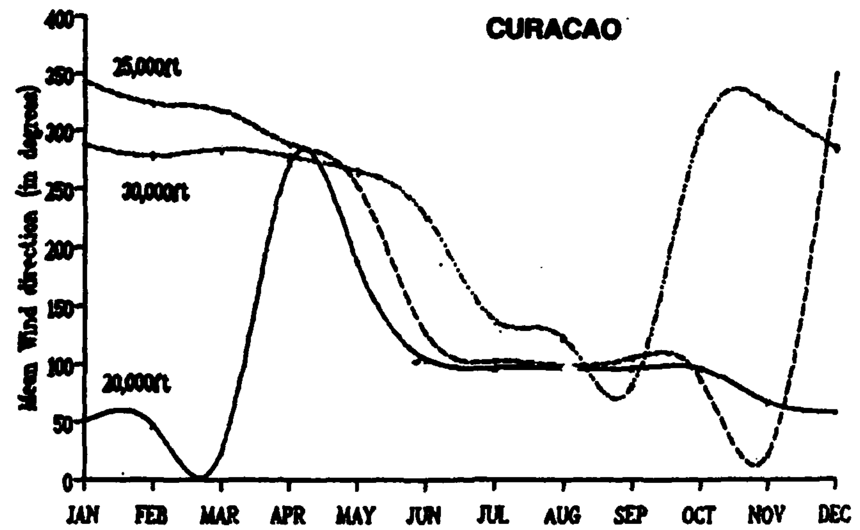


Figure 4-24b. Mean Upper-Level (20, 25, 30K) Winds at Curacao.

THUNDERSTORMS. Thunderstorms are infrequent, occurring on 1 day or less a month on most island locations. They are most likely to occur when the Monsoon Trough moves into the southern Caribbean. Isolated storms that form on the northern coast of Venezuela may reach the Southern Islands.

PRECIPITATION. Rainfall in the Southern Islands averages only 15 to 25 inches (381 to 635 mm) a year, most as sudden morning showers. During the dry season, there is less than 1 inch (25 mm) a month; many locations see less than half an inch a month. Although the terrain on most islands is too low to produce much of a windward/leeward effect, a slight increase in cloudiness and precipitation may occur on the windward side of Curacao's 1,220-foot (372-meter) peak. Showers that form off the eastern shores of the islands occasionally move onshore in the morning.

TEMPERATURES. Mean daily maximum temperatures are 83 to 85°F (28 to 29°C) in February, rising to near 90°F (32°C) in September. Mean daily minimums range from 74 to 77°F (24 to 25°C) in February, rising to near 80°F (27°C) in September.

SEA SURFACE TEMPERATURES. Mean sea surface temperatures in February are nearly equal to mean air temperature at 79°F (26°C). By August, air and sea surface temperatures are equal, at 82°F (21°C). Upwelling along the Northern Coast of Venezuela keeps mean sea surface temperatures 1 to 2°F (.6 to 1.2°C) lower than the Caribbean waters to the north. In 1958, Lahey reported sea surface temperatures as low as 72°F (22°C) in coastal waters near Margarita Island. These low sea temperatures help in creating the low-level inversion that increases stability.

GENERAL WEATHER. The actual beginning and ending of the wet season is tied to the seasonal northward shift of the polar westerlies, which disappear below 25,000 feet (7.6 km). The upper-level westerlies (at 25,000-40,000 feet/7.6 to 12.2 km) weaken during the wet season and may even disappear temporarily at its height. Paradoxically, low-level trade winds also weaken as the Azores High weakens and moves south. The trade wind inversion's mean height is 8,500 feet (2.6 km). Tropical disturbances, easterly waves, and the Monsoon Trough are the main wet season weather producers. These phenomena may continue into February or they may cease in December. In any case, the "wet" season can be said to have ended during the first month in which mean rainfall is less than 1 inch (25 mm) and during which very few transitory disturbances occur.

Northward oscillations of the Monsoon Trough may last for several days and bring periods of showers and thunderstorms; this phenomenon varies in frequency from year to year and is linked to the severity of the southern hemisphere winter. Although northward movement of the Monsoon Trough is influenced by the strength of South American polar outbreaks, the Southern Islands are afforded some protection by the Venezuelan Andes. The Monsoon Trough may still move over the northern coast of Venezuela in October, but not as often as in August and September.

Low-level convergence tied to the development of tropical cyclones on the Caribbean side of the Isthmus of Panama may occasionally cause considerable cloudiness and precipitation in the Southern Islands. Southwest winds around these disturbances move along the Venezuelan Andes, through Lake Maricaibo, and over the Southern Islands, joining the prevailing easterly flow and resulting in an extensive zone of convergence. See "Tropical Disturbances" for favored months and occurrence frequency.

Late in the wet season (by November), the stronger polar incursions from North America may also become a wet season factor. Polar fronts that reach the Southern Islands from the United States are greatly modified, with few remaining surface temperature discontinuities; only a wind shift boundary (shear line) remains to produce showers and thunderstorms ahead of, along, and behind the shear line. A slight temperature drop due to evaporative cooling, along with a wind shift toward north, may suggest the presence of a frontal passage. However, no such passage has ever occurred, at least by mid-latitude standards.

SKY COVER. Sky cover is basically the same as during the dry season--3 to 5 tenths cumulus or stratocumulus with some cirrus. Cloud bases are 2,000 to 3,000 feet (610 to 915 meters), but infrequently constitute a ceiling. Cloud tops average 6,000 to 8,000 feet (1.83 to 2.4 km). Visibility is 7 miles or better. Fog is rare. Light haze is often observed from the surface to the base of the trade wind inversion; on rare occasions, it may reduce visibility to 5 miles. Sudden showers may reduce visibility to near zero for very short periods. Ceilings and visibilities are below 3,000/3 10% of the time, and below 1,000/2 less than 2% of the time. The freezing level is near 15,000 feet (4.6 km).

WINDS The easterly trade winds prevail, with mean speeds of 13 to 15 knots. Polar outbreaks may disrupt this flow to result in northerly or northeasterly winds for a day or two. The islands in this group are too small to produce a perceptible land/sea breeze; the prevailing easterly trades mask any land/sea breeze effects. Winds are easterly to 30,000 feet (9.2 km) in October (see Figures 4-24a and b). They back to north-northwesterly above 30,000 feet (9.2 km), remaining northwesterly from 30,000 through 50,000 feet (15.2 km). Winds return to easterly above 60,000 to 65,000 feet (18.3 to 19.8 km).

TROPICAL DISTURBANCES. Only 13 storms have affected the Southern Islands from 1886 to 1963; 30% of those storms occurred in October, 8% in November, and 8% in December. Easterly waves--well developed surges in the trade winds--bring showers and thunderstorms with heavy rains. Although these waves vary in frequency from year to year, they do not normally occur after November. During years that the Monsoon Trough moves into the Southern Caribbean frequently, easterly waves are deflected north and are not common to the Southern Islands. During years when the Monsoon Trough stays south of the Caribbean, however, easterly waves may be expected to cross the region at fairly regular intervals of 5 or 6 days.

THUNDERSTORMS. Thunderstorms are most frequent in September and October, when average occurrence is on 3-5 days a month (see Figure 4-25). They can be associated with migratory disturbances or the Monsoon Trough. Air mass thunderstorms are possible, but very rare. Late-season thunderstorms may form over the northern coast of Venezuela and move north across the water to the Southern Islands.

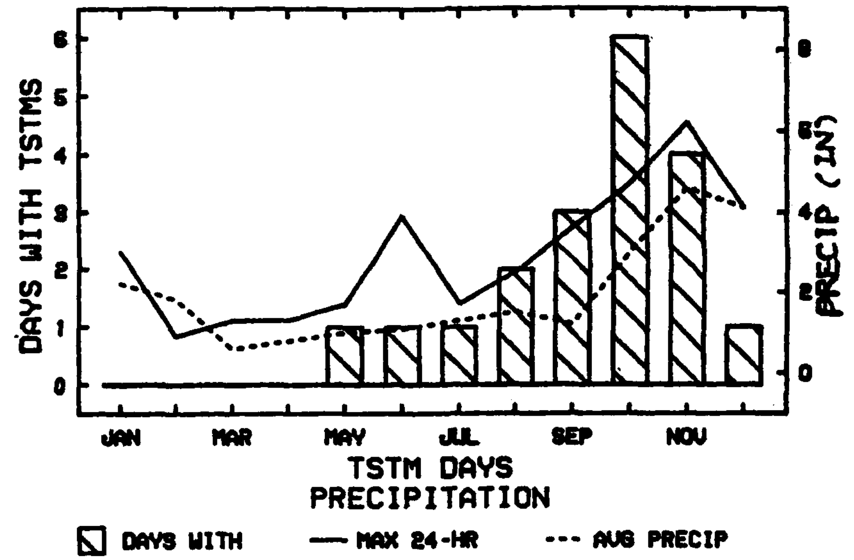


Figure 4-25. Annual Thunderstorm and Days Precipitation - Curacao.

PRECIPITATION. Mean monthly precipitation increases dramatically from less than 1 inch (25 mm) a month during the dry season to 3 to 5 inches (76 to 127 mm) a month in the wet season. Rainfall varies widely based on the path individual disturbances take. The generally flat island terrain here has little effect on precipitation. Rain usually falls as showers or thundershowers near transitory disturbances. Showers that form off the eastern shores of the islands at night may be carried onshore in the morning. The mean number of days with precipitation, nearly double that of the dry season, is still significantly less than on the rest of the more northerly islands in the Lesser Antilles. However, heavy precipitation events can occur under the influence of stronger tropical disturbances. Precipitation and cloud cover in the area of low-level convergence near the Monsoon Trough or under the terrain effects mentioned earlier can last for several days. Polar outbreaks from either hemisphere may bring showers that can last for a day or more.

TEMPERATURES Mean daily maximum temperatures are in the upper 80s°F (31 to 32°C). Mean daily minimums are in the mid- to upper 70s°F (24 to 26°C).

SEA SURFACE TEMPERATURES. Mean sea surface temperatures in October are nearly equal to the mean air temperature of 83°F (28°C). By January, mean air and sea surface temperatures are dead equal at 79°F (26°C). Upwelling along the northern coast of Venezuela maintains sea surface temperatures at several degrees less than the adjacent Caribbean waters to the North; this thermal contrast may help in creating a stabilizing low-level inversion.

4.3 CARIBBEAN OPEN WATERS

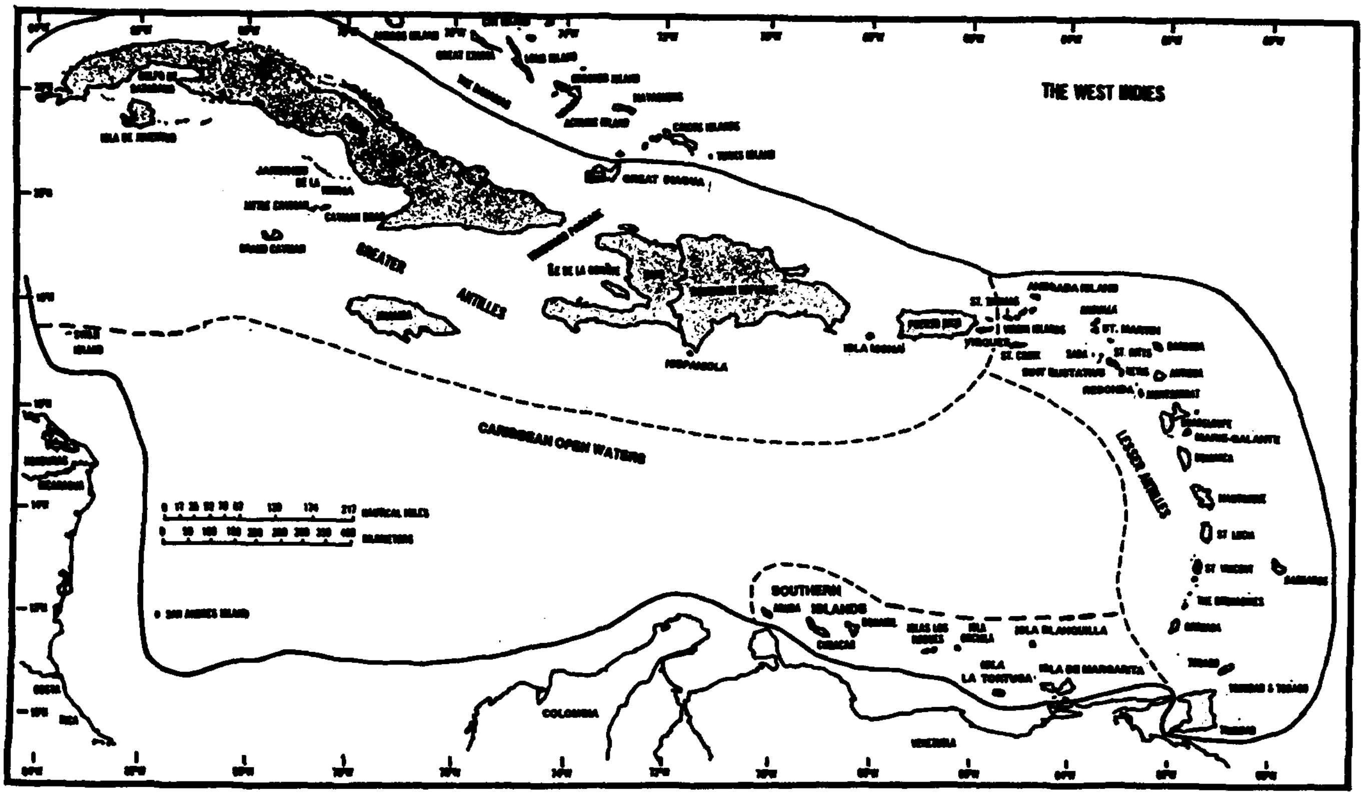


Figure 4-26. The Caribbean Open Waters Region. This region includes the "open waters" portions of the Yucatan Basin, the Colombian Basin, and the Venezuelan Basin. These waters will be discussed here independently of the major Caribbean land areas and their coastal waters. Although the authors have attempted to summarize the climate and weather of this vast "open waters" region, readers should note that the wide spatial extent of the area under discussion makes it unlikely that the entire region would ever see the same kind of weather at the same time. The climatology presented here, however, assumes a generally homogeneous area and points out only significant climatological differences. There are only two seasons in the open waters region, with no clearly identifiable transitions from one to the other: the dry season runs from December to April, and the wet season from May to November. These inclusive periods are approximate; actual beginning and ending times for each of the seasons can vary across the region.

GENERAL WEATHER. The "open waters" dry season is dominated by the easterly trade winds generated by flow around the Azores High. Still higher pressures are the result of numerous strong anticyclones that move south from North America. Ocean areas are normally in undisturbed flow; convection is capped by a strong trade-wind inversion. The base of the inversion is at 7,500 feet (2.3 km) MSL in the northern parts of the region, but slightly higher near South America, where bases average over 8,000 feet (2.4 km). Inversion bases show insignificant east-west variation. North American polar surges usually affect only the northern parts of the region, which see northerly winds, increased shower activity, and temperatures up to 10°F (6°C) cooler for 1 or 2 days until the trade wind inversion and easterly trade winds are reestablished. True "frontal" weather is much modified as surges move deeper into the Caribbean, but convection will occur wherever the trade wind inversion is temporarily weakened. Over most of the open waters region, however, the dry season produces only high pressure, upper-level subsidence, and dry weather.

SKY COVER. Dry season clouds are typically cumulus and trade wind stratocumulus with bases at 2,000 to 4,000 feet (610-1,220 meters) and tops at 6,000 to 8,000 feet (1.8 to 2.4 meters). Cloud amounts are between 3 and 5 tenths. In undisturbed situations, the eastern portion of the region sees cloud tops near 7,000 feet (2.1 km) due to a lower and stronger trade wind inversion. Cloud tops in the western portion may range between 7,000 and 10,000 feet (2.1 to 3.1 km). Diurnal variation in cloud cover over open water is different than over land. Empirical observation has recently been supported by satellite and radar studies that indicate a "double diurnal maximum" of convective cloud cover; it has been found that open water areas see an early morning primary low cloud maximum at 2,000 to 3,000 feet (610 to 915 meters), with another secondary maximum in late afternoon.

Polar outbreaks cause significant increases in cloud cover, especially in the northern and western portions of the region. Towering cumulus, stratocumulus, and cumulonimbus are all possible in the vicinity of mid-latitude frontal zones. Cloud bases remain near 2,000 feet (610 meters), except in heavy precipitation. Average cloud tops are usually no more than 10,000 to 15,000 feet (3.1 to 4.6 km), but cumulonimbus tops of 20,000 to 25,000 feet (6.1 to 7.6 km) are not unusual. In stronger polar surges, post-frontal streets of stratocumulus can be expected as cold air moves over the warm waters of the Caribbean; this phenomenon, which is seen south of the island of Cuba only with the strongest surges, is shown in Figure 4-27. Strong northerly surges are followed by subsidence resulting from passage over high terrain on Cuba and the Yucatan Peninsula. This drier air, carried far downwind over the open sea, discourages normal fair weather cumulus.

On rare occasions, an extremely strong polar outbreak may reach the Venezuela and Caribbean Colombian coasts, which see. Such outbreaks produce towering cumulus, stratocumulus, and cumulonimbus along the old frontal boundary. Altocumulus and altostratus are found in the immediate vicinity of cumulonimbus, the tops of which may reach 35,000 feet (11 km) over open seas.

Figure 4-27. The "Cloud Street" Effect. GOES-East visual, 1600Z 29 February 1984.

WINDS. Dry season winds are easterly at low levels and westerly at upper levels. The depth of the easterlies increases from north to south. Westerlies begin just over 10,000 feet (3.1 km) in the north, while easterlies extend to 25,000 to 30,000 feet (7.6 to 9.2 km) near South America. The winter mean position of the Azores High (35° N) insures that the mean pressure (and therefore the mean wind speed) increases from north to south. Mean speeds are between 12-14 knots in the northern half of the region and between 15-20 knots in the southern half. Low-level winds behind polar outbreaks can be northeasterly (even northwesterly), with gusts greater than 25 knots, but the easterlies are soon reestablished. "Channeling" of wind flow between some islands can increase wind speeds slightly--see Figure 4-28. The terrain of southern Central America and northern South America can also cause low-level winds to turn to the northeast. Coastal frictional effects and land/sea breezes are discussed elsewhere in this chapter.

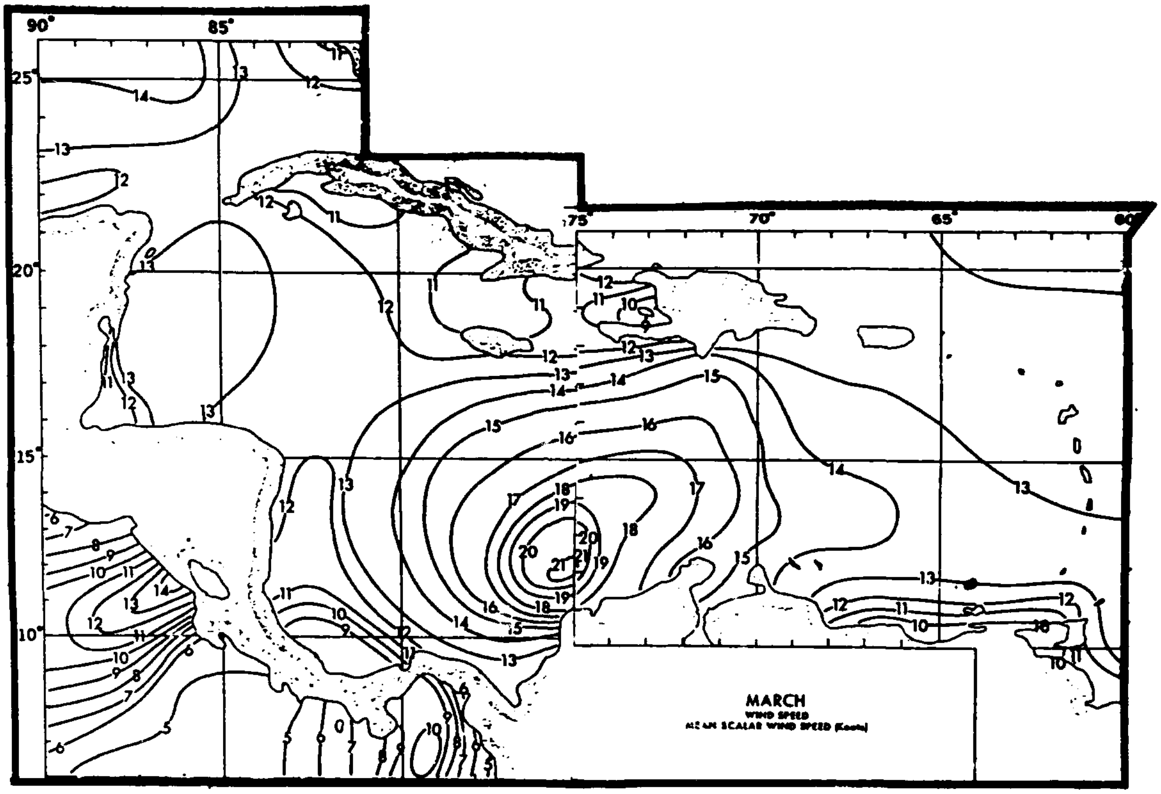


Figure 4-28. Mean Scalar Wind Speeds (knots) for March.

THUNDERSTORMS. During the dry season, thunderstorms occur on less than half a day a month. As in the entire Caribbean Basin, air mass thunderstorms are virtually unknown during the dry season, when thunderstorms are associated with migratory disturbances--either mid-latitude polar surges from December to March, or tropical disturbances (easterly waves and tropical storms) in April. Thunderstorm tops are generally less than 30,000 feet (9.2 km) except in the strongest and most deeply penetrating surges, when tops may reach 35,000 feet (11 km).

PRECIPITATION. Prolonged rainfall is rare except during passage of a polar front or upper-level trough. When a mid-latitude disturbance becomes stationary, precipitation can occur over small areas for several days. A north-to-south variation in precipitation is much less noticeable during the dry season. Thanks to the lack of consistent observational data on the open seas, mean monthly precipitation figures are difficult to determine. However, based on amounts reported from stations on small, flat islands in the open waters region, mean rainfall is probably between 2 to 3 inches (51 to 76 mm)

a month. Although measurable precipitation probably falls on 8-10 days a month, the actual number of events can vary from year to year. As is the case with cloud cover, diurnal variation in precipitation over open water is different than over land. Recent evidence shows that there is also a "double diurnal maximum" of precipitation over open water areas, with a primary maximum just before sunrise and another in late afternoon.

TEMPERATURES. Mean air temperatures over open seas are controlled by the mean sea surface temperatures, which are generally within a few degrees of each other (see Figure 4-29). During the dry season, the usual diurnal temperature change is evident. Day-to-day fluctuations in temperature can be caused by rainshowers or by cooling behind a mid-latitude polar outbreak, which can lower temperatures by 5-10 degrees, but only for 24-36 hours. As warm Caribbean waters modify polar air masses, temperatures rise quickly to prefrontal levels. Mean highs over most of this region are in the low- to mid-80s°F (28 to 30°C); mean lows are in the low to mid 70s°F (22 to 24°C). Temperatures show little variation in latitude except in the northern quarter of the region near Cuba and the Yucatan Peninsula, where temperatures are about 5°F cooler.

SURFACE CURRENTS. The coolest sea surfaces in the open waters region are off the northern coasts of Cuba, where January temperatures drop to 77°F (25°C). Along the northern coasts of Colombia and Venezuela, upwelling results in January sea surface temperatures of 78°F (26°C) or less. These represent the northern and southern extremes; sea temperatures in the rest of the region are at their coolest (79-80°F or 26°C) in January through March.

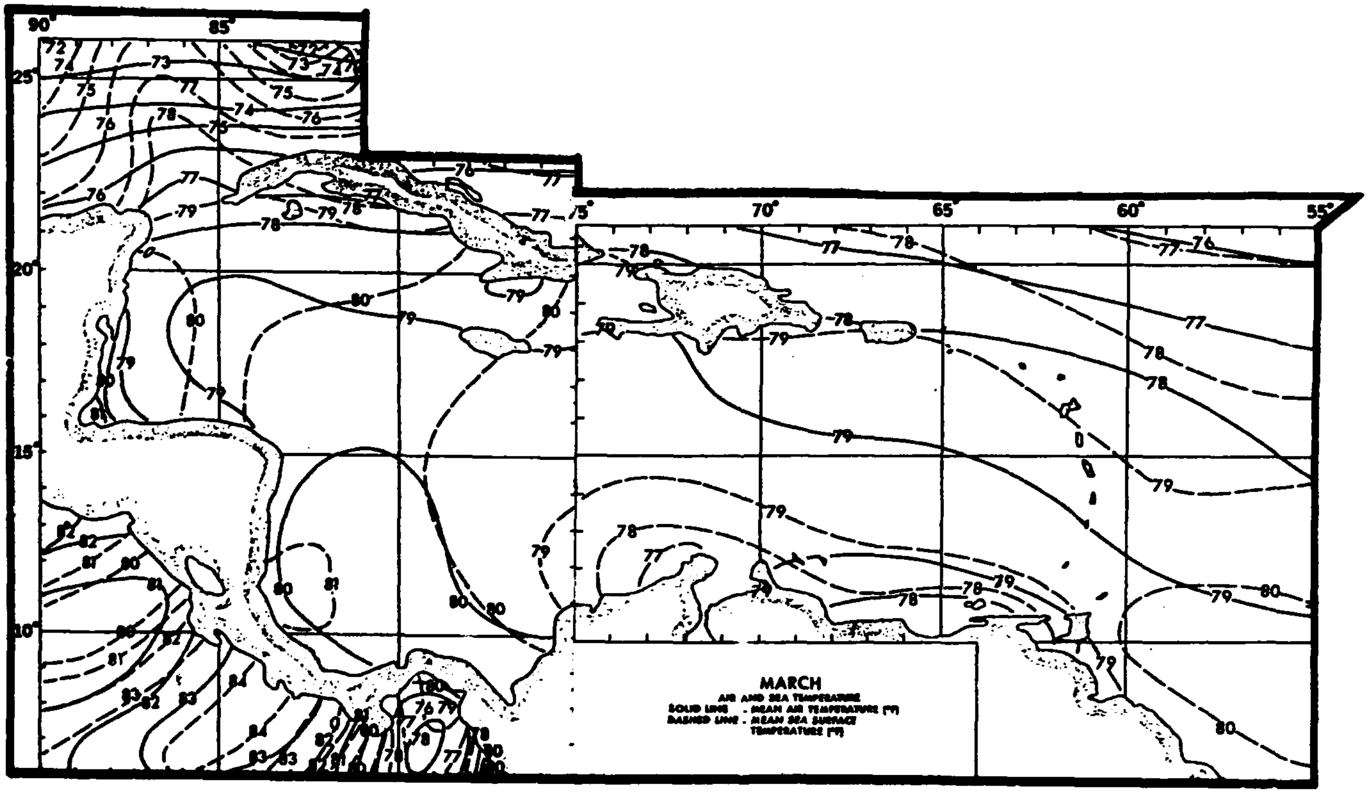


Figure 4-29. Mean Air and Sea Temperatures (F) for March.

SURFACE CURRENTS. Predominant surface flow in the Caribbean is provided by the Antilles Current, which starts in the Lesser Antilles and moves westward with a mean vector of 280 to 300 degrees. Southeasterly surface flow persists throughout the year over nearly the entire Caribbean Basin. Its flow is easterly as it parallels the coast of northern South America. But as it reaches the northern coast of Nicaragua, the current splits, with one branch going south, the other north--both paralleling the coastlines. The water flowing south past Costa Rica and Panama is eventually deflected north, setting up cyclonic turning off the Colombian coast.

GENERAL WEATHER. Wet season weather over open waters has the same causes as over the islands of the West Indies. As the Azores High moves northward, the trade wind inversion weakens and rises; the result is a general increase in instability and convective cloud cover. Although most wet season precipitation occurs over land (and most of that over mountainous terrain), rainfall also increases over water. The wet season is marked by the development and passage of tropical disturbances that bring cloud cover and precipitation. The Monsoon Trough can also contribute to wet season rainfall by moving into the southern Caribbean where it remains for extended periods and affects a wide latitudinal band over the open waters region.

SKY COVER. Even with an increase in daily trade wind cumulus and the occasional tropical disturbance, mean monthly cloud cover only increases to 5-6 tenths (from the dry season's 4-5 tenths). Mean heights of bases are still between 2,000 and 3,000 feet (610 to 915 meters). The greater height of the trade wind inversion is reflected in mean cloud top height increases to between 8,000 and 9,000 feet (2.4 to 2.7 km). Near the Monsoon Trough and in the vicinity of tropical disturbances, an entire range of cloud types can be found, including towering cumulus, altocumulus, and cumulonimbus.

During the wet season, the islands of the West Indies have several affects on clouds seen over open waters. First, middle and high clouds can be advected eastward from clouds that have been orographically produced over mountainous islands. The strong easterly trades carry these clouds hundreds of miles from their places of origin, a phenomenon that helps explain some of the late night cloud cover seen over regions of open water. Another phenomenon here is the development of long cloud streets that extend downwind from certain islands of the West Indies. These cloud streets, which can also occur in the dry season, are oriented parallel to the prevailing trade wind flow. They are composed of cumulus and towering cumulus and can produce rainshowers as far as 30 to 60 NM away from the islands. Figure 4-30 shows that even the smallest of the Virgin islands (Anegada) can produce this persistent phenomenon.

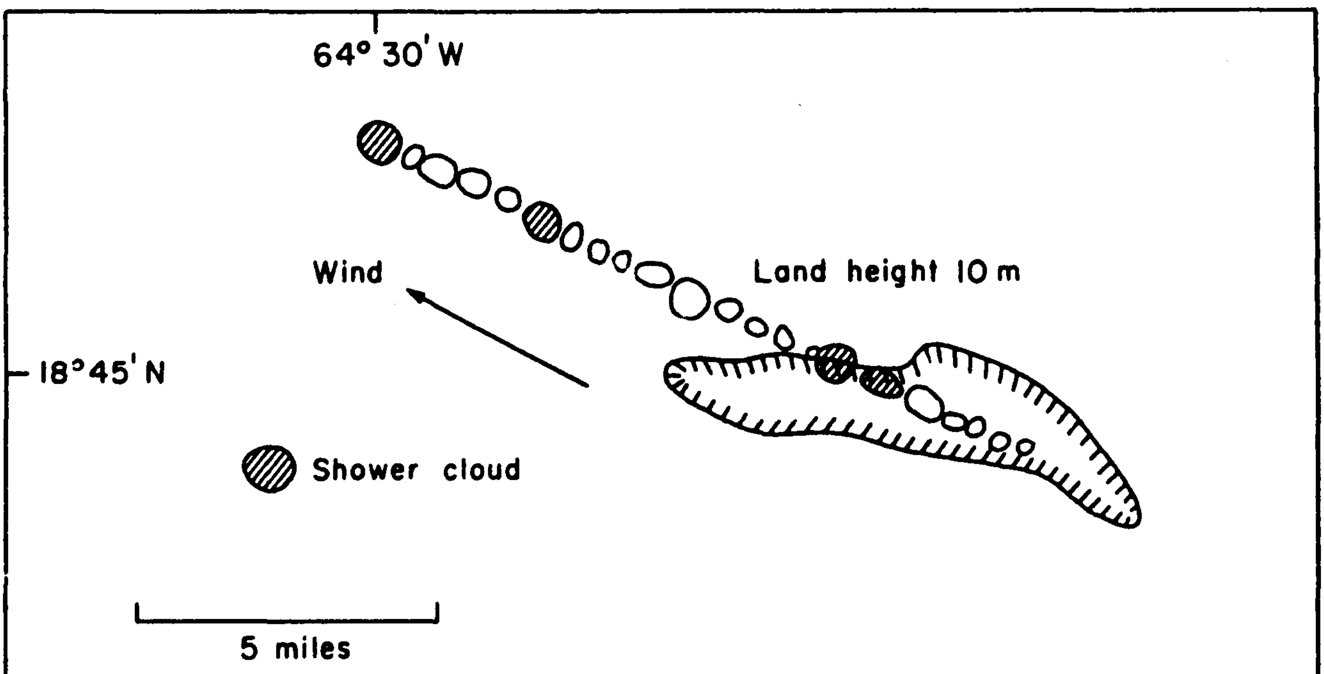


Figure 4-30. Cloud Streets Over the Small Island of Anegada in the Virgin Islands. This illustration is based on actual observations from 26 March 1953. The "streets" have formed near noon and are extending far downstream.

WINDS. Easterly trade winds continue to dominate. Low-level flow is easterly, occasionally becoming southeasterly when the Azores High, at its strongest during the wet season, is displaced northward. Variations in flow are found in the vicinity of the tropical disturbances that are common during the wet season. Mean speeds are 12-15 knots through most of the wet season, increasing to 15-20 knots in June and August (see Figure 4-31). As in the dry season, mean speeds increase from north to south, with a band of strongest winds north of and parallel to northern South America. Winds are also highly variable near the Monsoon Trough when it moves into the southern Caribbean. Winds south of the Trough can be southeasterly (or even southwesterly), depending on the location of southern hemisphere oceanic and continental anticyclones.

Wet season easterly flow generally extends to a greater depth throughout the region, running from the surface to 20,000 feet (6.1 km) in the northern portions, and from the surface to 40,000 feet (12.2 km) in the south. Mean wet season speeds are much more uniform than during the dry season; speeds are 10-20 knots from 5,000 feet (1.5 km) to 30,000 feet (9.2 km). In the south, they increase with height to 40 knots at 50,000 feet (15.3 km).

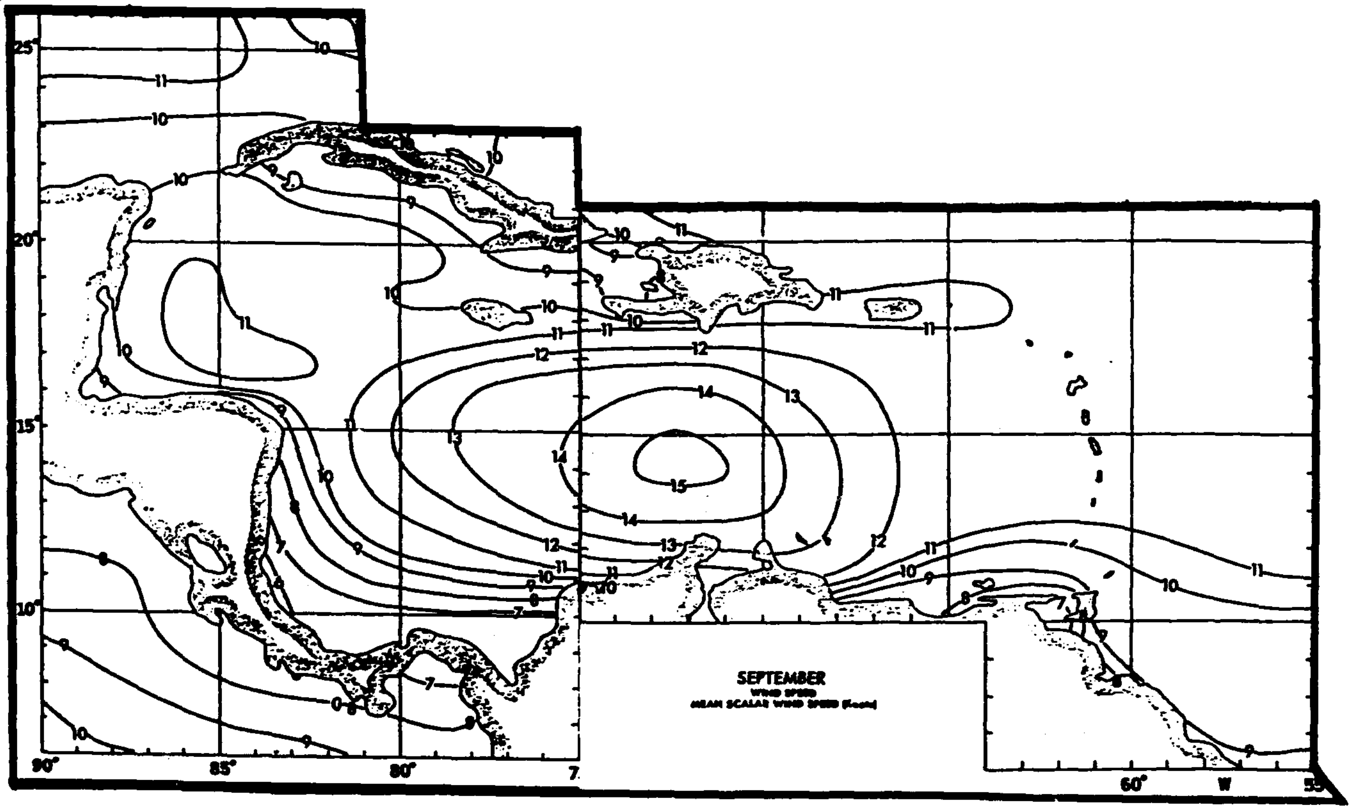


Figure 4-31. Mean Scalar Wind Speeds for September.

TROPICAL DISTURBANCES. The storm season runs from May through the end of November, but August, September, and October are most favored. The many possible areas for development and numerous typical storm tracks guarantee tremendous variety in the effect these storms can have on any given open water area. Some southern open seas, for example, see tropical disturbances only rarely, while other areas are affected very frequently. Easterly waves in the trade winds typically begin to cross the region in late May or June, but stop by November. Waves typically move through the Caribbean every 4 to 6 days, but the routine varies from year to year. Easterly waves bring increased cloudiness, showers, and thunderstorms. A torrential rainfall of 8 inches (203 mm) in 24 hours has been recorded. Waves may intensify into tropical storms and hurricanes.

THUNDERSTORMS. Based on frequencies noted at reporting stations on smaller islands, wet season thunderstorms occur on 3-5 days a month across the open waters region. They may originate with tropical disturbances or the Monsoon Trough, or they may be blown out to sea from larger islands by the easterly trade winds. Although thunderstorms rarely occur in undisturbed flow, they can form in the evening when radiational cooling at the tops of clouds causes additional vertical development.

PRECIPITATION. Prolonged rainfall is rare except during passage of a tropical disturbance or easterly wave, or in the vicinity of the Monsoon Trough. Thanks to a lack of consistent observational data on the open seas, mean monthly precipitation figures are difficult to determine. However, based on amounts reported by stations on small, flat islands in the open waters region, mean wet-season rainfall is probably between 4 and 6 inches (102 and 152 mm) a month. Measurable precipitation probably falls on 10-15 days a month, but the actual number of events can vary from year to year. As was the case with cloud cover, diurnal variation in precipitation over open water is different than over land. Recent evidence shows a "double diurnal maximum" of precipitation over open water, with a primary maximum just before sunrise and another in late afternoon.

TEMPERATURES. There is little temperature change during the wet season. Mean air temperatures over the ocean are controlled by mean sea surface temperatures, but air and sea temperatures are generally within a few degrees of each other (see Figure 4-32). Precipitation may produce several hours of cooling, but temperatures rise again quickly. Mean daily maximums are in the mid- to high 80s°F (30 to 32°C), with minimums in the mid- to high 70s°F (24 to 26°C). Temperatures show little latitudinal variation except in the northern quarter of the region later in the period, when the mid-latitude disturbances of winter reappear.

SEA SURFACE TEMPERATURES. The coolest sea surfaces are found along the northern coast of South America, where mean sea surface temperatures are below 80°F (27°C) throughout the wet season. Coastal upwelling here can be attributed to strong winds and low-level divergence. North of 15° N, average June-October sea surface temperatures are 83 to 84°F (29°C). Late in the wet season, the cooler air temperatures of winter are reflected in a 2-3°F gradient in sea surface temperatures in the waters near Cuba and the Yucatan Peninsula.

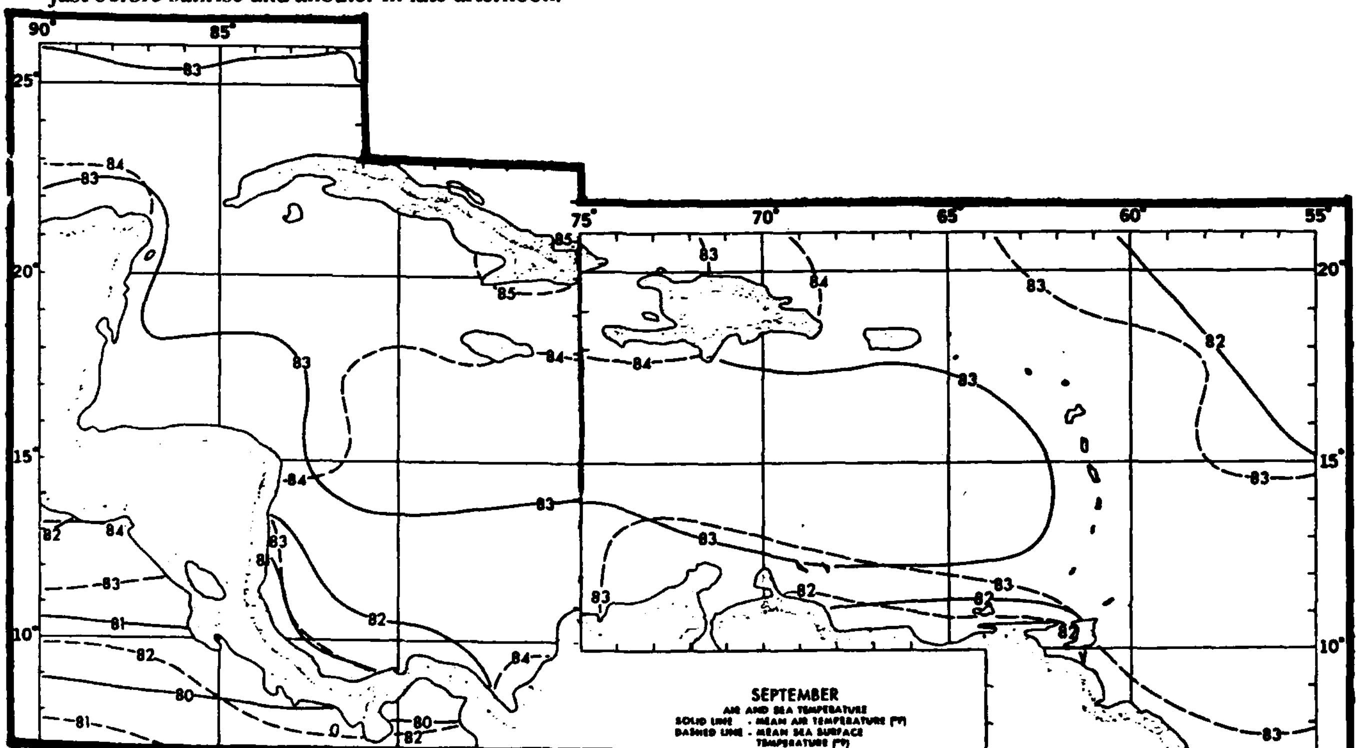


Figure 4-32. Mean Air and Sea Temperatures (°F) for September.

Chapter 5

NORTHERN SOUTH AMERICA

This chapter describes the situation and relief, major climatic controls, geography, and general weather of Northern South America, a geographical grouping that includes most of the territory North of the Amazon River. This area includes all of Colombia, Ecuador, Venezuela, Guyana, Suriname, French Guiana, and those portions of Brazil and Peru north of the Amazon. For the purposes of this study, the area is divided into eight climatologically similar lowland regions and one massive mountain area, the Andes.

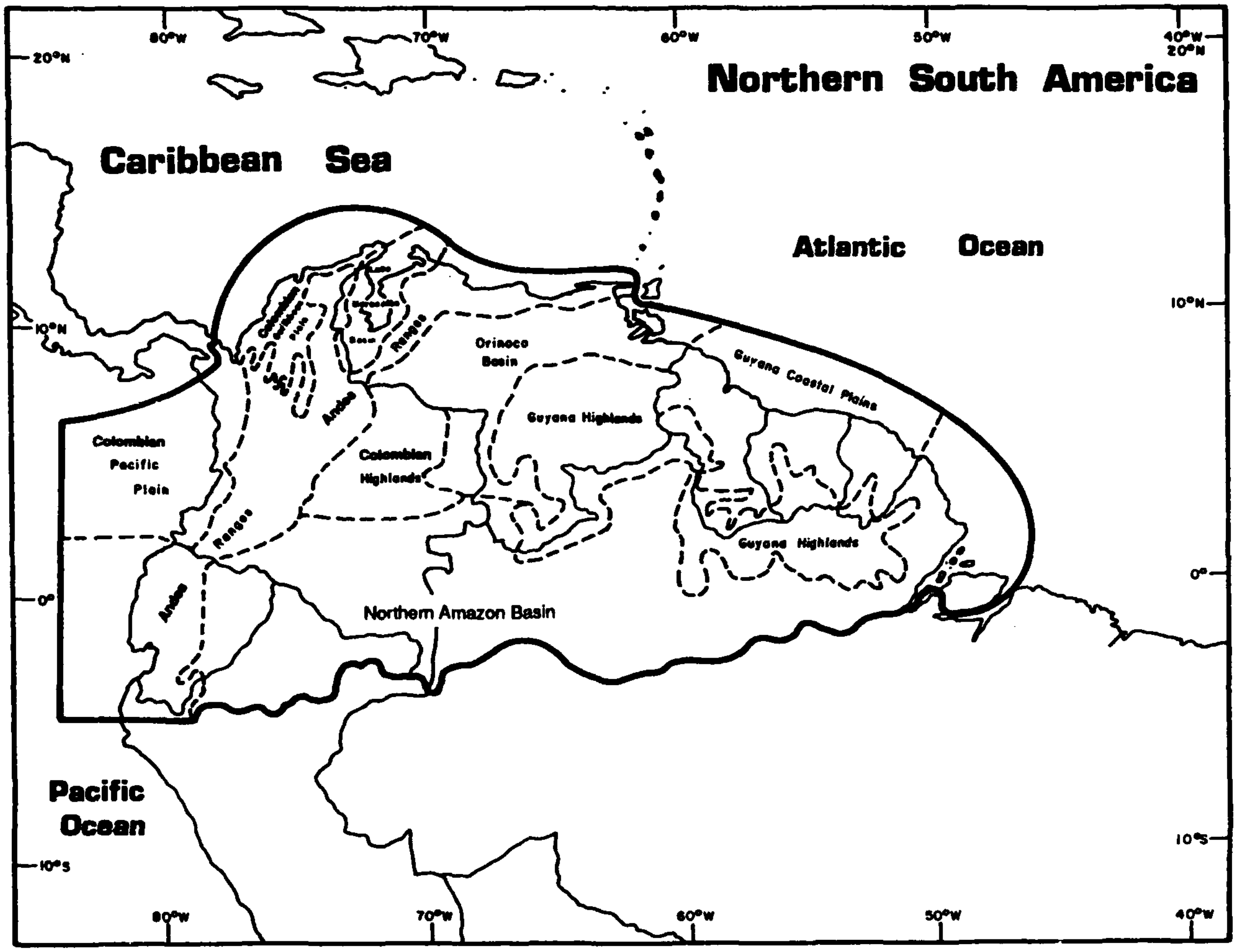


Figure 5-1. The Seven Geoclimatological Regions of Northern South America.

NORTHERN SOUTH AMERICA

SITUATION AND RELIEF. For the purposes of this study, "Northern South America" is defined as that portion of the continent north of the Amazon Riv:r and its River Maranon westward extension. Specifically, the study region includes: Peru north of the Rio Maranon, Brazil north of the Amazon, Ecuador, Colombia, Venezuela, Guyana, Surinam, and Cayenne. It does not include Venezuela's offshore islands or Trinidad (see the West Indies), or Panama (see Central America). For the specific purposes of this study, we have divided Northern South America into nine regions of topographical and climatological commonality. These regions, each of which is discussed in turn, are shown in Figure 5-1.

Northern South America covers an area that extends almost 1,800 NM (3,480 km) from the mouth of the Amazon to the Pacific Peruvian coast. It extends 1,100 NM (2,130 km) from the Amazon to Lake Maracaibo. A remarkable variety of terrain and vegeation is found here, along with a wide range of climatic regimes. The region is dominated by two major river systems--the Orinoco and the Amazon--and a massive mountain complex, the Andes.

The Orinoco and Amazon rivers dominate the lowlands east of the Andes. The Orinoco drains much of the northern half of the region east of the Andes. The Amazon complex drains the southern half of the region, along with much of central South America. Of the two river systems, the Amazon (along with its jungles and rain forests) has the greater effect on this region's climate by providing an ever-present source of water vapor for air advected inland from the Atlantic. Dew points at Iquitos, for example, which is nearly 1,400 NM (2,710 km) inland from the Atlantic, are as high (or slightly higher) than at Belem, which is on the Atlantic coast. The continuous replenishment of water vapor lost to rain and cloud cover results in a what amounts to a year-round rainy season in the western Amazon and on eastern Andean ranges below 5,000-6,000 feet (1,525-1,830 meters).

The Andes range extends from Cape Horn to the Caribbean and east along the Venezuelan coast to Trinidad, where that island marks the range's geological termination. Mean elevations in Colombia and Ecuador are 14,000 to 17,000 feet (4,270 to 9,450 meters).

MAJOR CLIMATIC CONTROLS. The sheer size, height, and orientation of the massive Andes range has these three important meteorological results:

(1) The lower tropospheric Monsoon Trough is effectively split between the Pacific coast and the Amazon/Orinoco Basin. Above 18,000 feet (5,490 meters), it is virtually continuous across the continent. Except during those brief periods in which the Trough "pops" into the Caribbean, the Pacific and South American-Atlantic lower tropospheric troughs move independently of each other. As a result, wet and dry seasons at similar latitudes do not coincide.

(2) Low-level equatorial westerlies in the true monsoon sense are almost never found east of the Andes, and the extremely heavy precipitation found along the Pacific Colombian coast is not repeated east of the Andes. Recurved southern hemisphere air, however, does flow over the Colombian Highlands and the Orinoco Basin south of the Monsoon Trough from June through September. Whether or not this flow is properly referred to as an "equatorial westerly" is still controversial.

(3) Along the eastern Andes south of 2° N, forced lift of extremely warm and moist air from the Amazon Basin causes almost daily thunderstorms during the wet season, and on nearly 1 day in 4 during the so-called "dry" season.

Figures 5-2, 5-3, and 5-4 show annual, wet season, and dry season thunderstorm days, respectively. Because there are so very few aviation weather reporting stations along the eastern Andes, the thunderstorm frequencies given here are not reflected in summarized climatological data. Instead, these numbers were drawn from various other climatological summaries, from GOES satellite photographs, and from miscellaneous published papers. In addition, some of the data used here came from discussions between the senior author and a number of Brazilian, Colombian, Venezuelan, and American airline meteorologists with experience in this region. Note that thunderstorm frequencies along the eastern Andes may be even higher than those shown here.

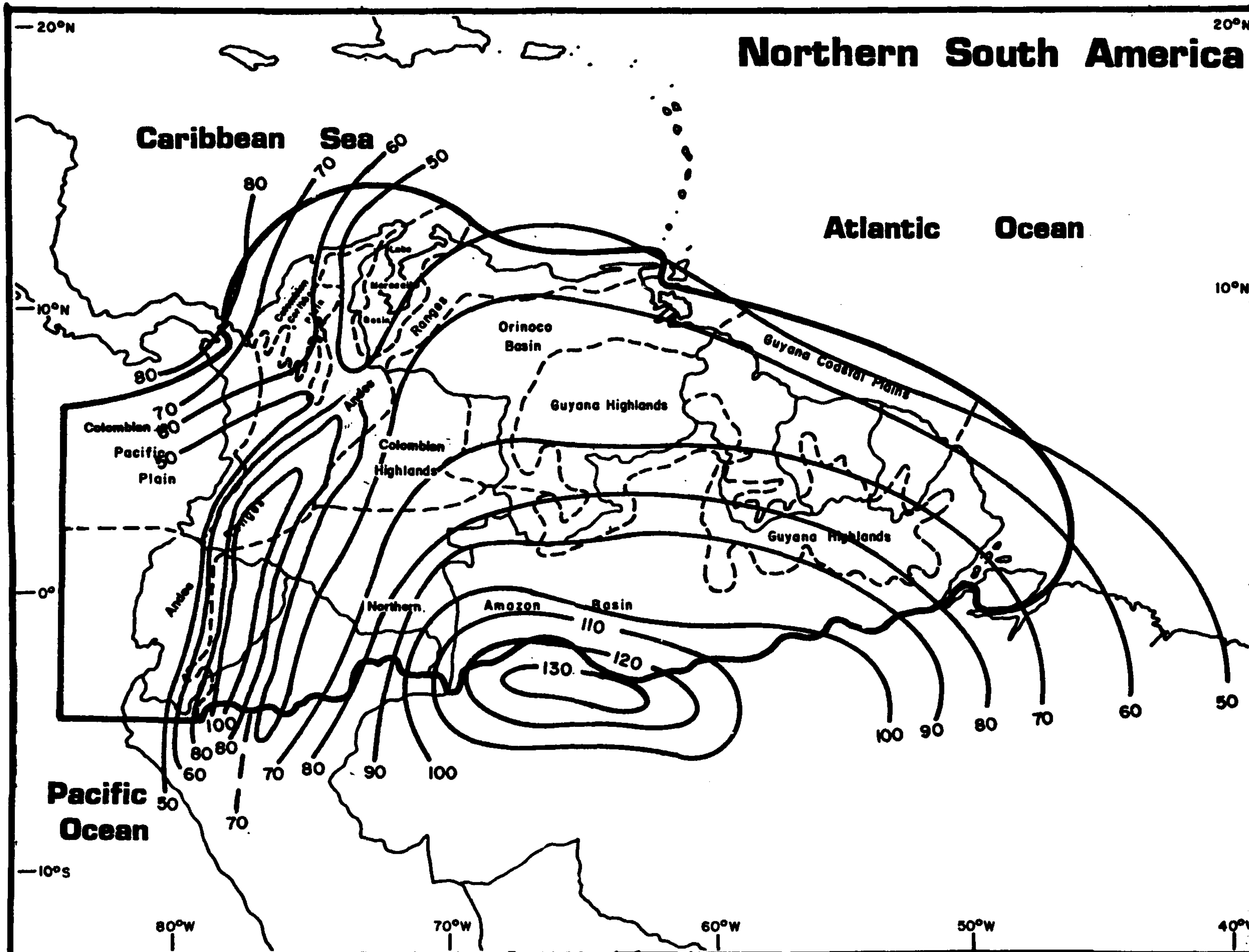


Figure 5-2. Annual Thunderstorm Days.

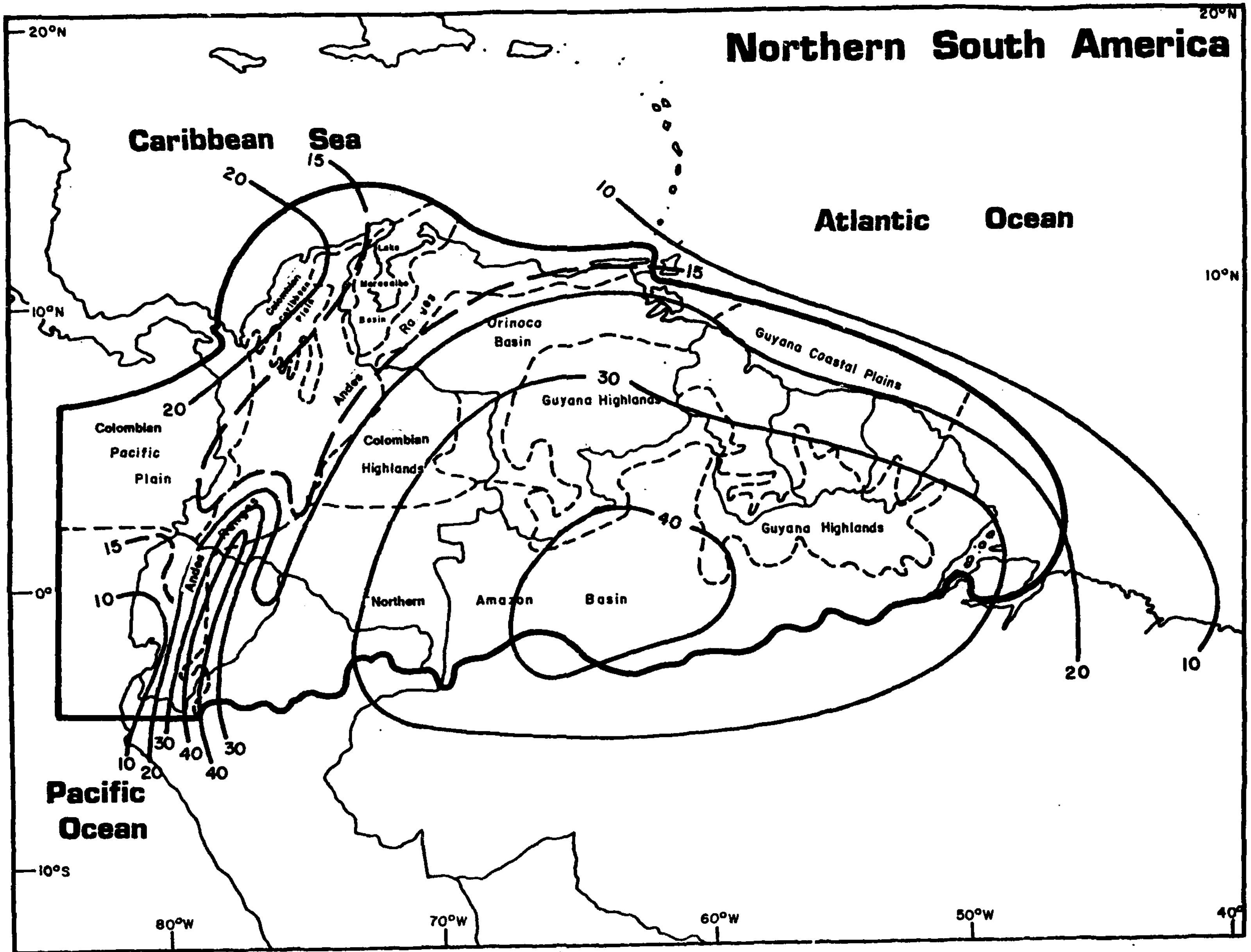


Figure 5-3. Dry Season Thunderstorm Days.

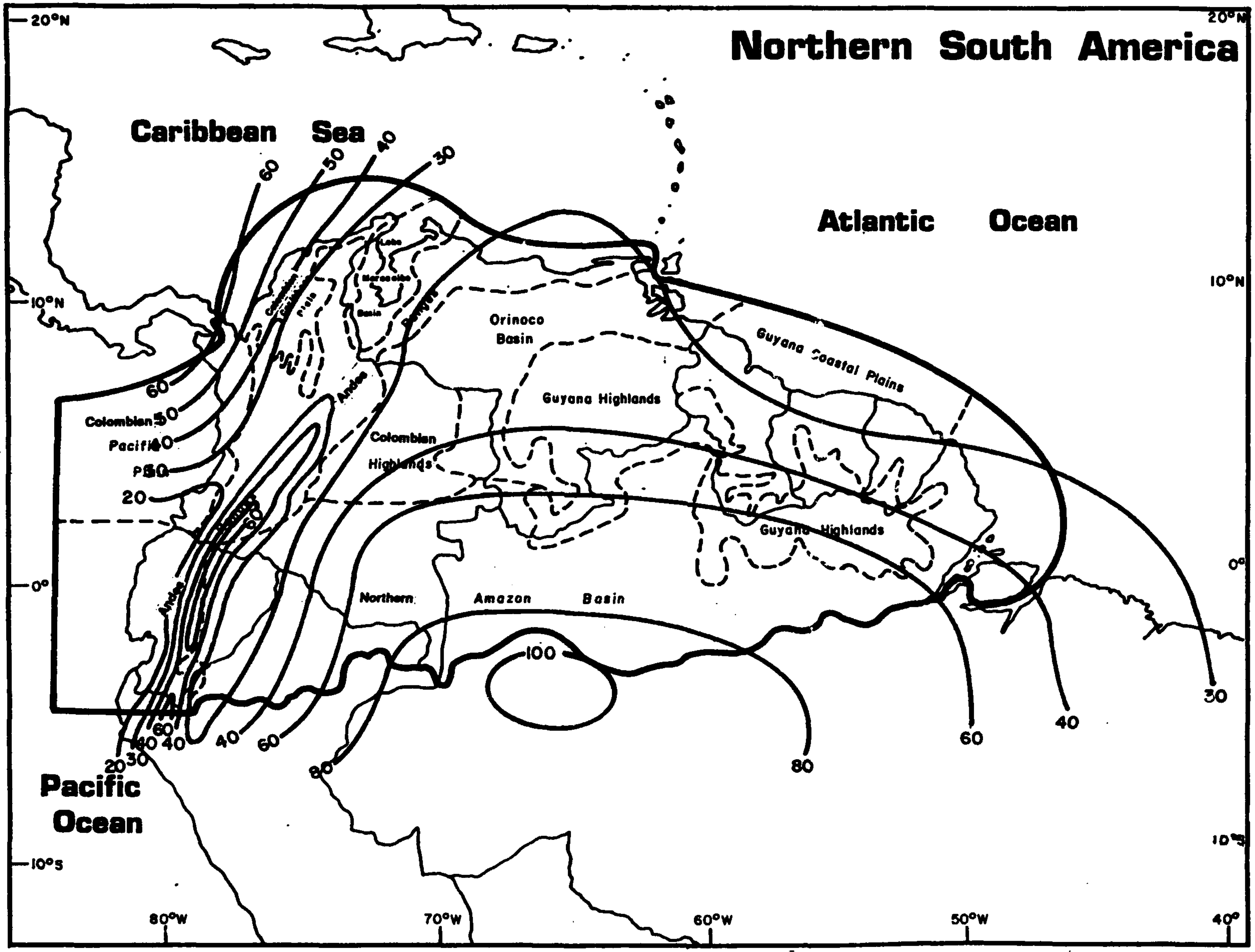


Figure 5-4. Wet Season Thunderstorm Days.

5.1 THE COLOMBIAN PACIFIC COASTAL PLAIN

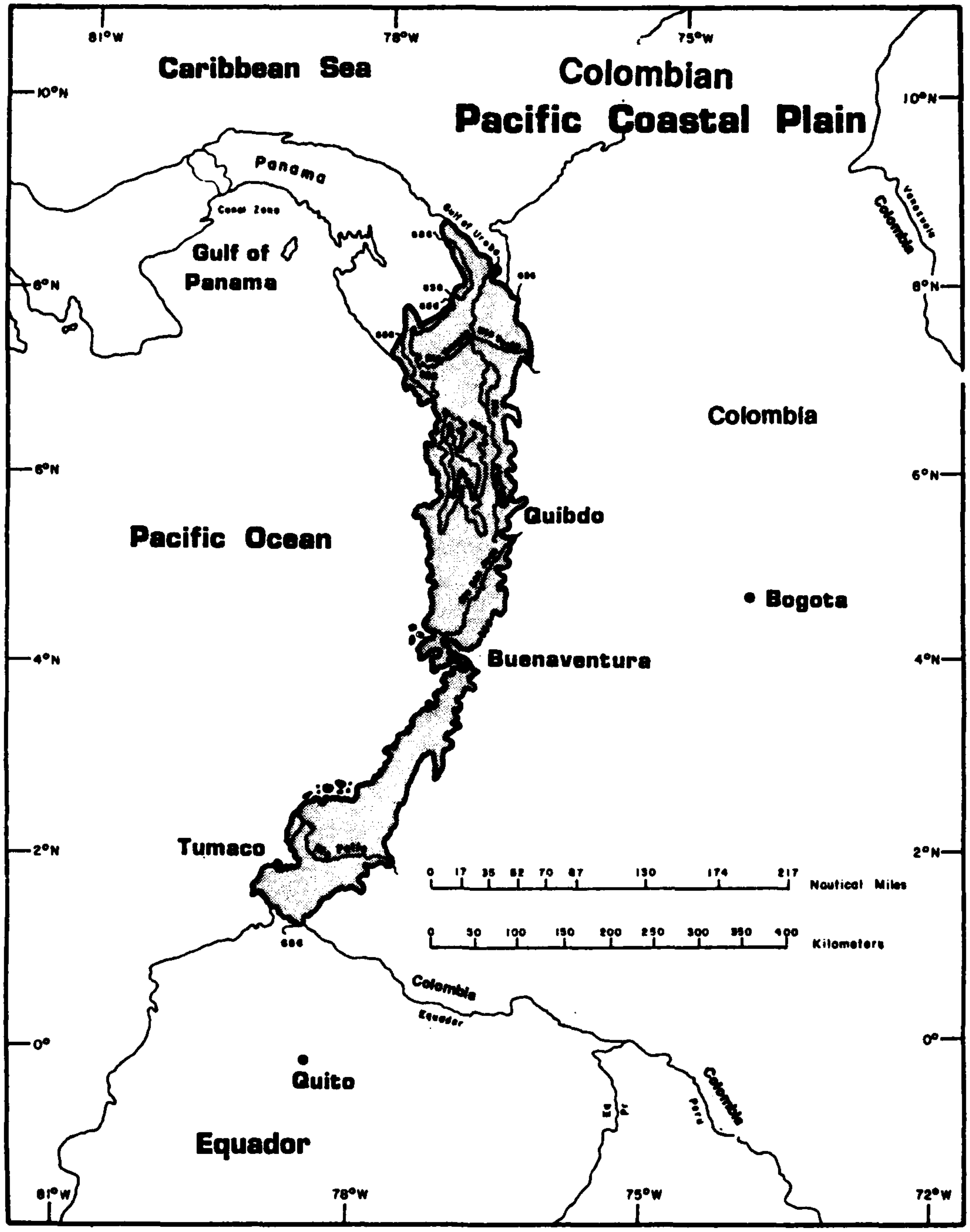


Figure 5-5. The Colombian Pacific Coastal Plain. With extremely heavy precipitation the year around, this region enjoys no real "dry season," as such. There are, however, minor letups in rainfall during May and June, and again in September.

COLOMBIAN PACIFIC COASTAL PLAIN GEOGRAPHY

BOUNDARIES. The Colombian Pacific Coastal Plain is bounded on the south by the Ecuador-Colombia border, on the west by the Pacific Ocean, and on the north by the Uraba Gulf. On the east, the boundary follows the 656-foot (200-meter) contour line on the eastern side of the Atrato River (Rio Atrato) to 5° N, then southward along the 656-foot/200-meter contour of the western Andean range to the Ecuadorian border.

TERRAIN. North of 5° N, the Baudo Mountains (highest elevation 3,328 feet/1,000 meters) rise inland immediately off the Pacific coast. This range, about 40 miles (65 km) wide, separates the Atrato River valley from the Pacific. A low east-west ridge, a spur from the western Andean range at an elevationof 500 feet/150 meters, separates the Atrato drainage from areas to the south. The Atrato itself turns eastward toward its origin in the western Andes.

From 5° N to the south, the coastal plain slopes upward and eastward toward the western Andean range. Its width varies from 30 to 60 miles (45 to 95 km).

VEGETATION. In the Atrato River valley below 500 feet (150 meters), vegetation in the immediate area of the river consists of evergreen swamp, dense wet scrub, and marsh, with some palms. Patches of deciduous forest, scrub, and grass grow in drier areas. At the mouth of the Atrato around the Uraba Gulf, mangrove swamps predominate.

Along the Atrato side of the Baudo Mountains between 500 feet (150 meters) and the range crests, two-tiered tropical rain forests predominate. Height of the canopy averages 100 feet (30 meters).

West of the Baudo Mountain crest, dense evergreen highland forest reaches to the coast line. Trees reach 85 feet (26 meters); undergrowth is dense.

South of 5° N, the coastline to 5 to 10 miles (8 to 16 km) inland consists of dense mangrove swamp forest, gradually changing to tropical rain forest.

GENERAL WEATHER. There are no distinct "wet" or "dry" seasons in this region. Precipitation, which is so heavy all year as to result in what amounts to a year-round wet season, increases during July and early August as the Monsoon Trough oscillates. The exact reasons for the Trough's oscillations during this period are obscure, but it is interesting to note that the phenomenon occurs simultaneously with the westward and northward movement of the western lobe of the Azores High. The increased subsidence that accompanies this movement has been identified as the cause of the "little dry season" in Central America. A logical presumption would be that this is also the cause of the Monsoon Trough's oscillations over the extreme eastern equatorial Pacific. Remember, however, that the north Pacific High has virtually no influence on the equatorial Pacific off Central America.

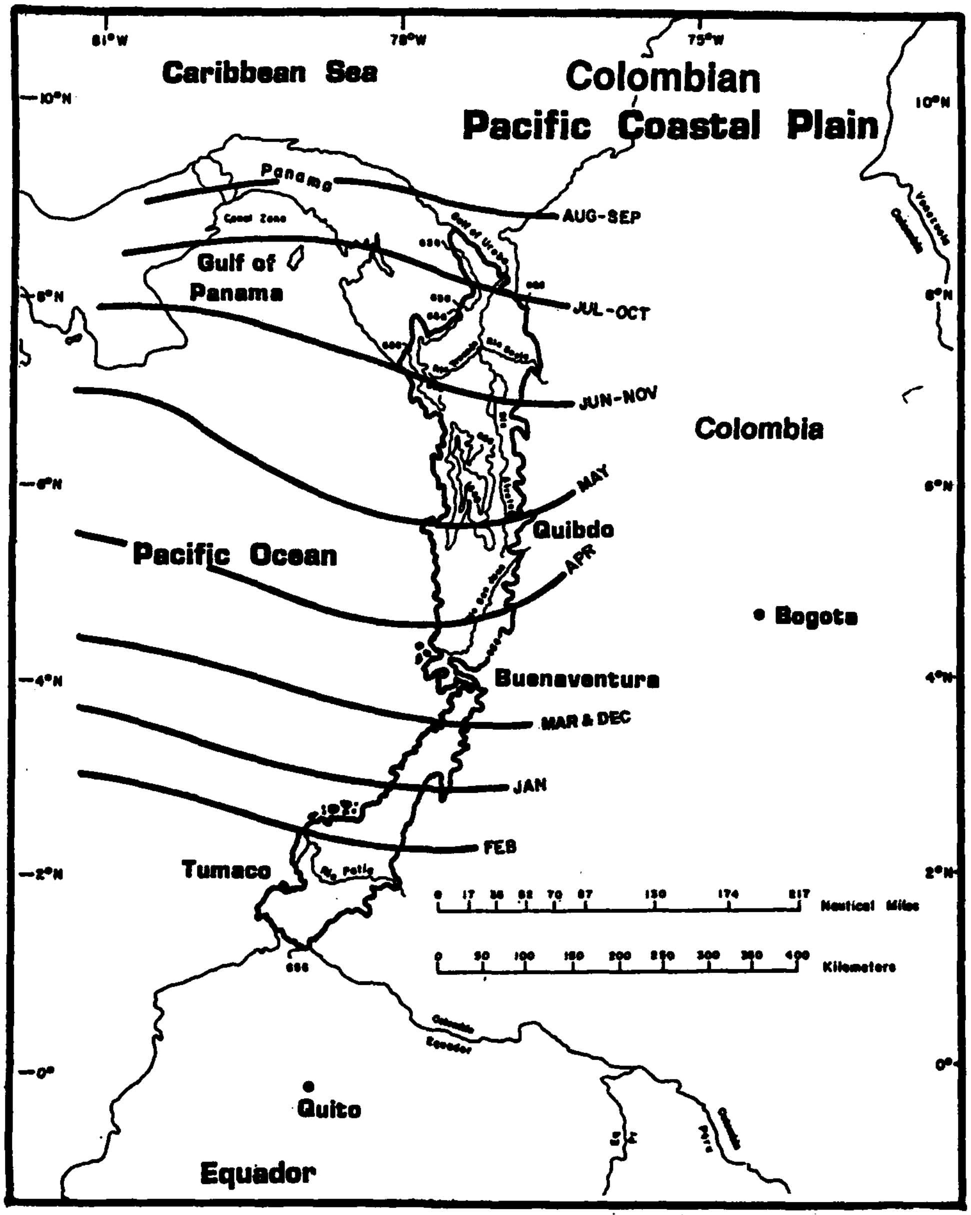


Figure 5-6. Monsoon Trough Positioning. During August and September, the Monsoon Trough is just north of the Pacific Coastal Plain. It is not coincidental that August and September see the maximum rainfall in the extreme northern parts of the region.

Recurved southern hemisphere southeasterly trade winds become equatorial westerlies that occur south of the Monsoon Trough to near 1° N. The deeper westerlies occur with the most northerly Monsoon Trough positions. Representative low-level flow is shown (at 3-month intervals) in Figure 5-7.

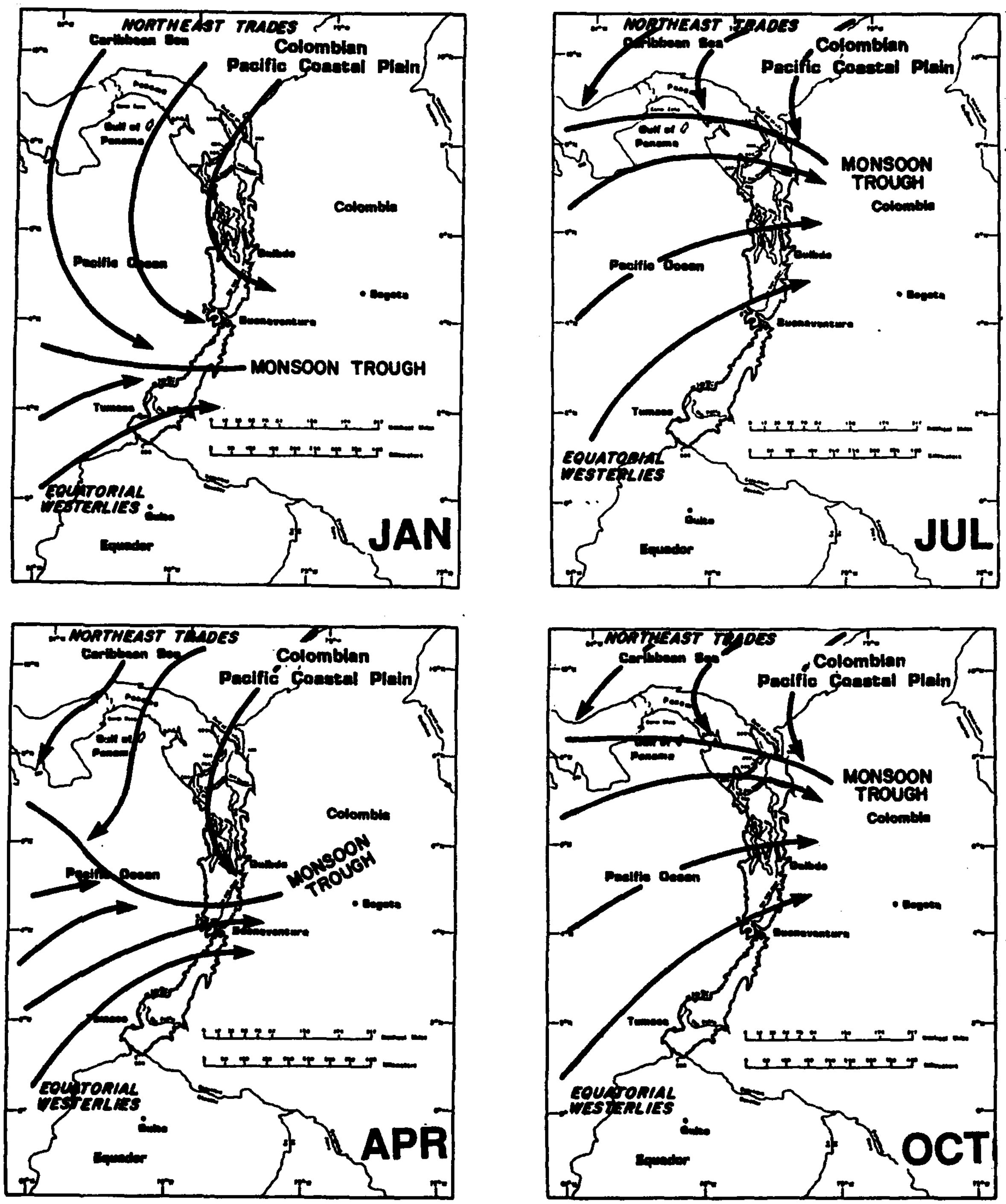


Figure 5-7. Mean Low-Level Flow.

SKY COVER. Even with the extremely heavy rainfall here, weather has a diurnal cycle. At dawn, cloud cover is thick stratus/stratocumulus and cumulus, with bases at 500 to 1,000 feet (150 to 305 meters) and tops between 3,000 and 6,000 feet (915 and 1,830 meters). Visibilities beneath the clouds range from 1 to 3 miles (1.6 to 4.8 km) in drizzle and light rain. By late morning, clouds have dwindled to 4-7/10 stratocumulus with bases at 1,500 to 2,000 feet (455 to 610 meters) and tops from 4,000 to 5,000 feet (1,220 to 1,525 meters). Visibilities improve to 5-7 miles, with only widely scattered light rain showers. By mid-afternoon, stratocumulus and cumulus increase. By sunset, skies are overcast with stratus, stratocumulus, and/or cumulus, with bases at 1,000 to 1,500 feet (305 to 455 meters) and tops from 5,000 to 7,000 feet (1,525 to 2,135 meters). Visibilities drop to 3-5 miles in light rain or drizzle. By 2100 LST, light rain showers begin as the first heavy cumulus of the evening appears, with tops to 12,000 feet (3,660 meters).

Scattered embedded heavy cumulus and isolated cumulonimbus appear at midnight and persist til dawn; bases are 300 to 500 feet (90 to 150 meters). Cumulonimbus tops can reach 40,000 feet (12.2 km).

During trade wind surges, heavy cumulus and cumulonimbus increase in coverage and intensity. Although a surge can occur at any time, the most favored time is from late afternoon through dawn.

Representative mean monthly daylight ceiling and visibility curves for three Colombian stations (Quibdo, Buenaventura, and Tumaco) are shown in figures 5-8, 5-9, and 5-10, respectively. Buenaventura and Tumaco are on the immediate coast, while Quibdo is inland, in the Andean foothills. Although the frequency of visibilities less than 7 miles varies from station to station, the frequency of ceilings below 3,000 feet is very similar.

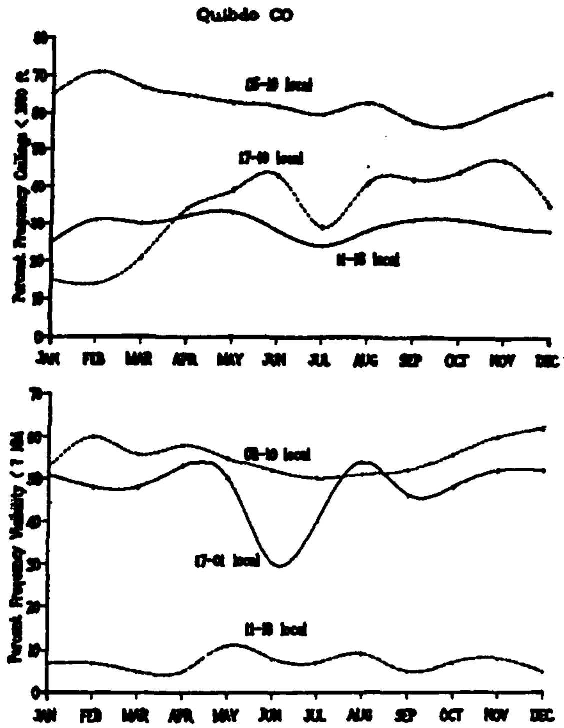


Figure 5-8. Percent Frequency Ceiling and Visibility <3,000/7: Quibdo, Colombia.

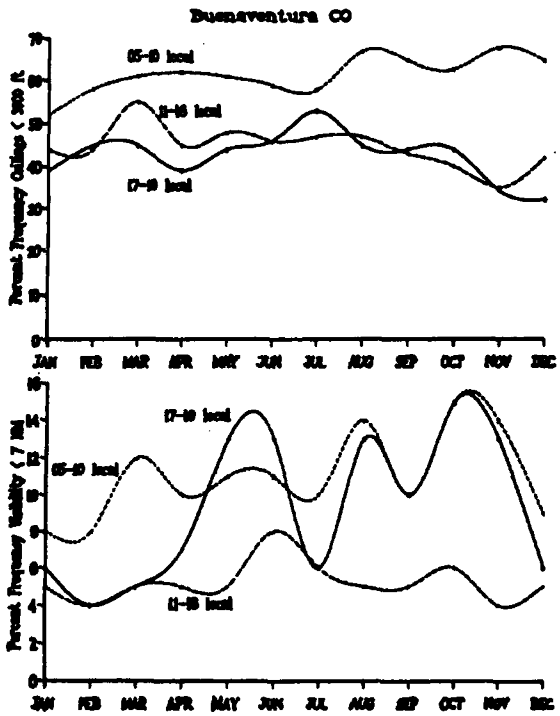


Figure 5-9. Percent Frequency Ceiling and Visibility <3,000/7: Buenaventura, CO.

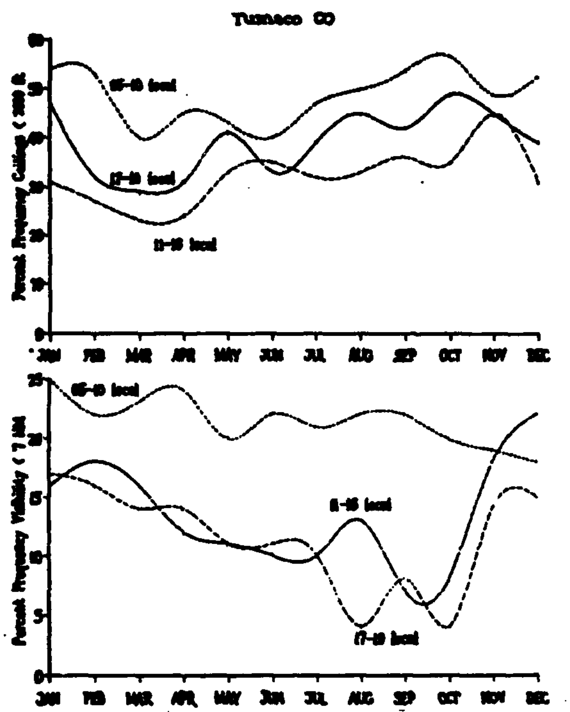


Figure 5-10. Percent Frequency Ceiling and Visibility <3,000/7: Tumaco, Colombia.

WINDS. Onshore coastal winds are southwesterly, regardless of the exact location of the Monsoon Trough. Speeds average 5 to 15 knots.

THUNDERSTORMS are rare. Those that do occur form over the mountains and are blown west during the evening by the upper-level easterlies.

PRECIPITATION is heavy all year, with minor letups in late May and early June, and again in September, during northward surges of the Monsoon Trough. Studies by Colombian meteorologists suggest that mean annual rainfall on certain mountain ridges between the coast and Quibdo may be as much as 472 inches, or 12 meters! If true, this part of Colombia could be the wettest spot on the planet! Figure 5-11 shows mean annual precipitation--in millimeters--on the coastal plain, while Figures 5-12a-c show mean monthly precipitation. The rainfall data in these figures, taken from the *WMO Climatic Atlas of South America*, is considered the best available for this country.

TEMPERATURE. Lows range from 75 to 77°F (23 to 24°C); highs from 81 to 83°F (27 to 28°C).

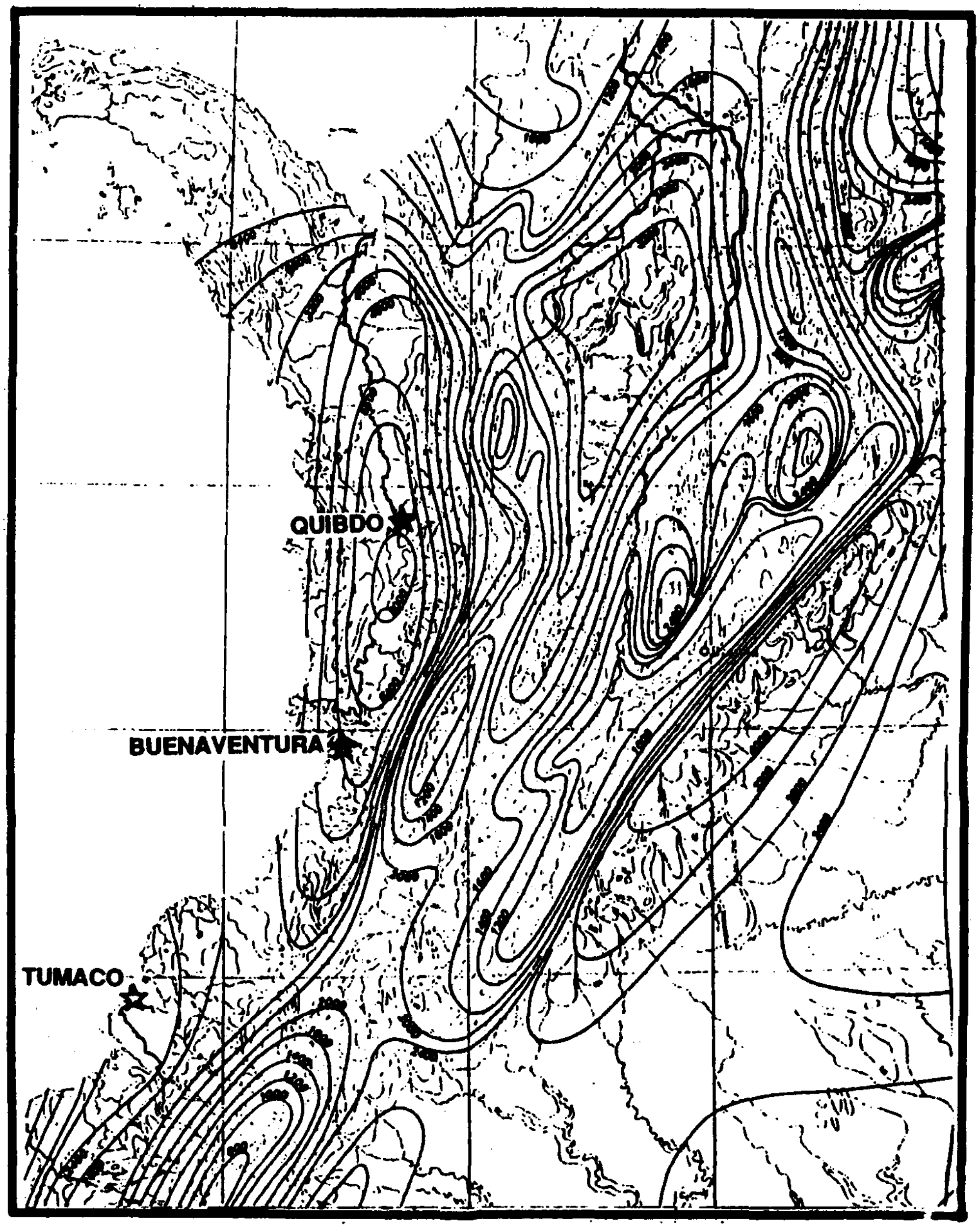


Figure 5-11. Mean Annual Precipitation.

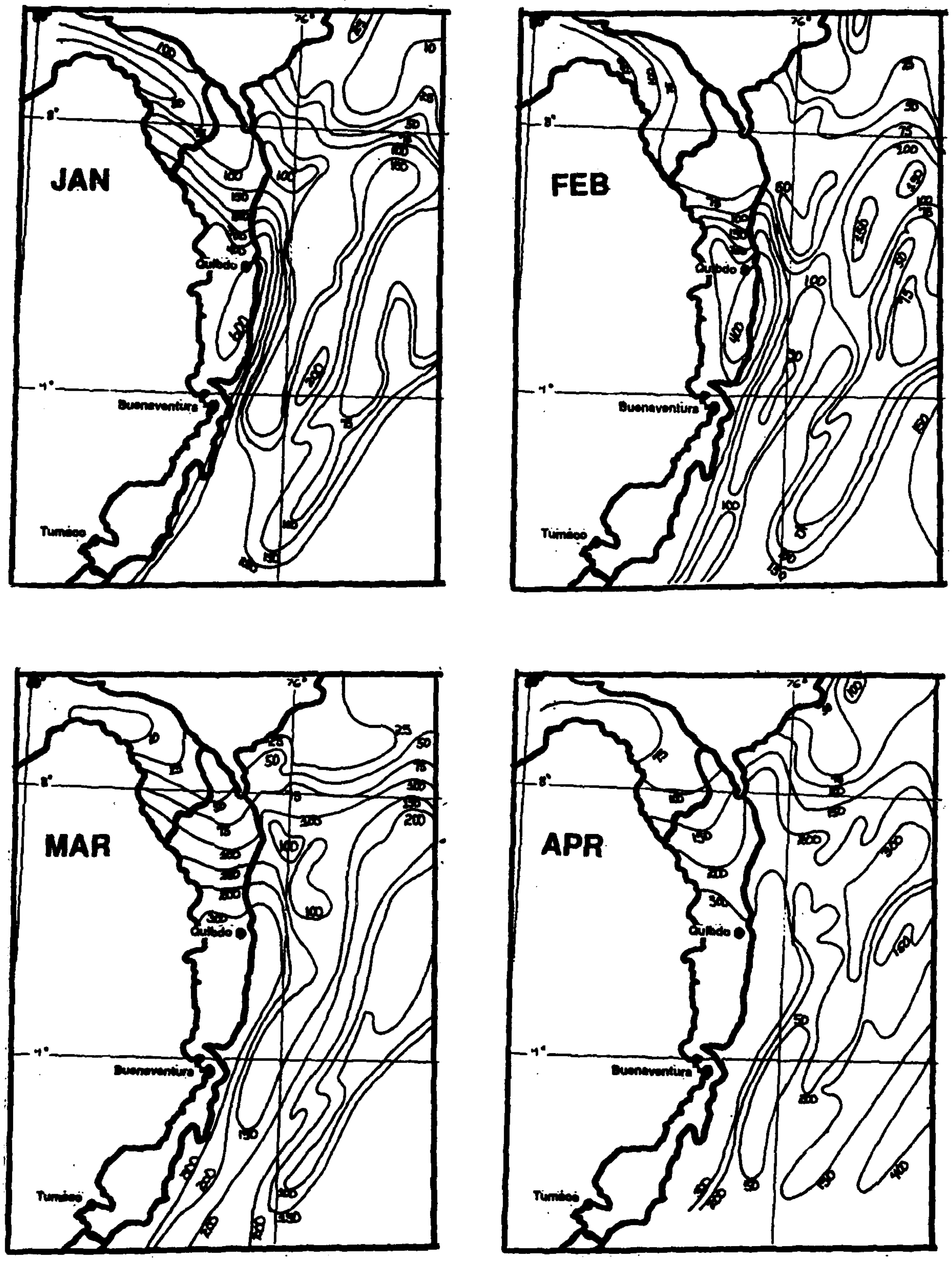


Figure 5-12a. Mean Monthly Precipitation: January-April.

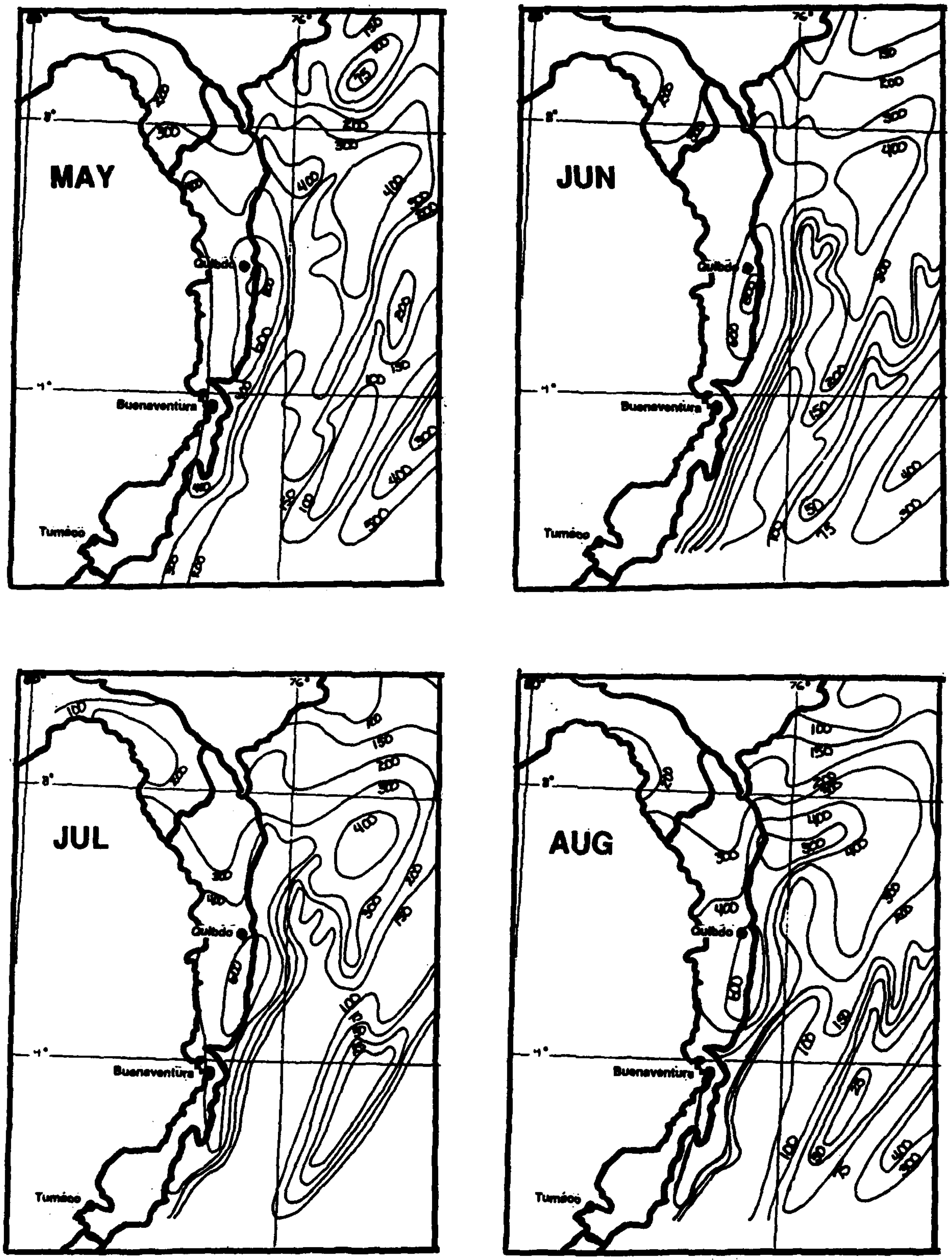


Figure 5-12b. Mean Monthly Precipitation: May-August.

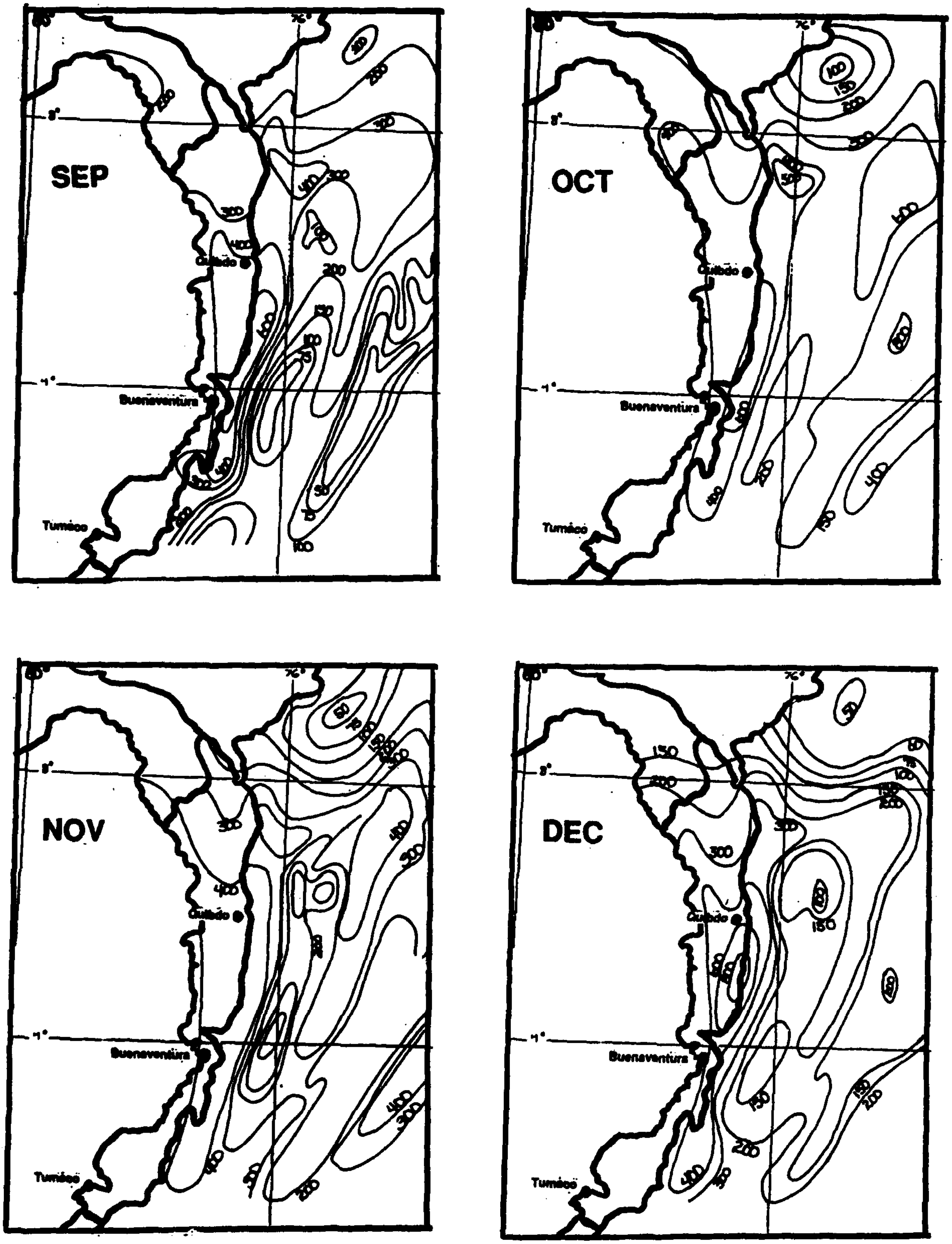


Figure 5-12c. Mean Monthly Precipitation: September-December.

5.2 THE COLOMBIAN CARIBBEAN COASTAL PLAIN

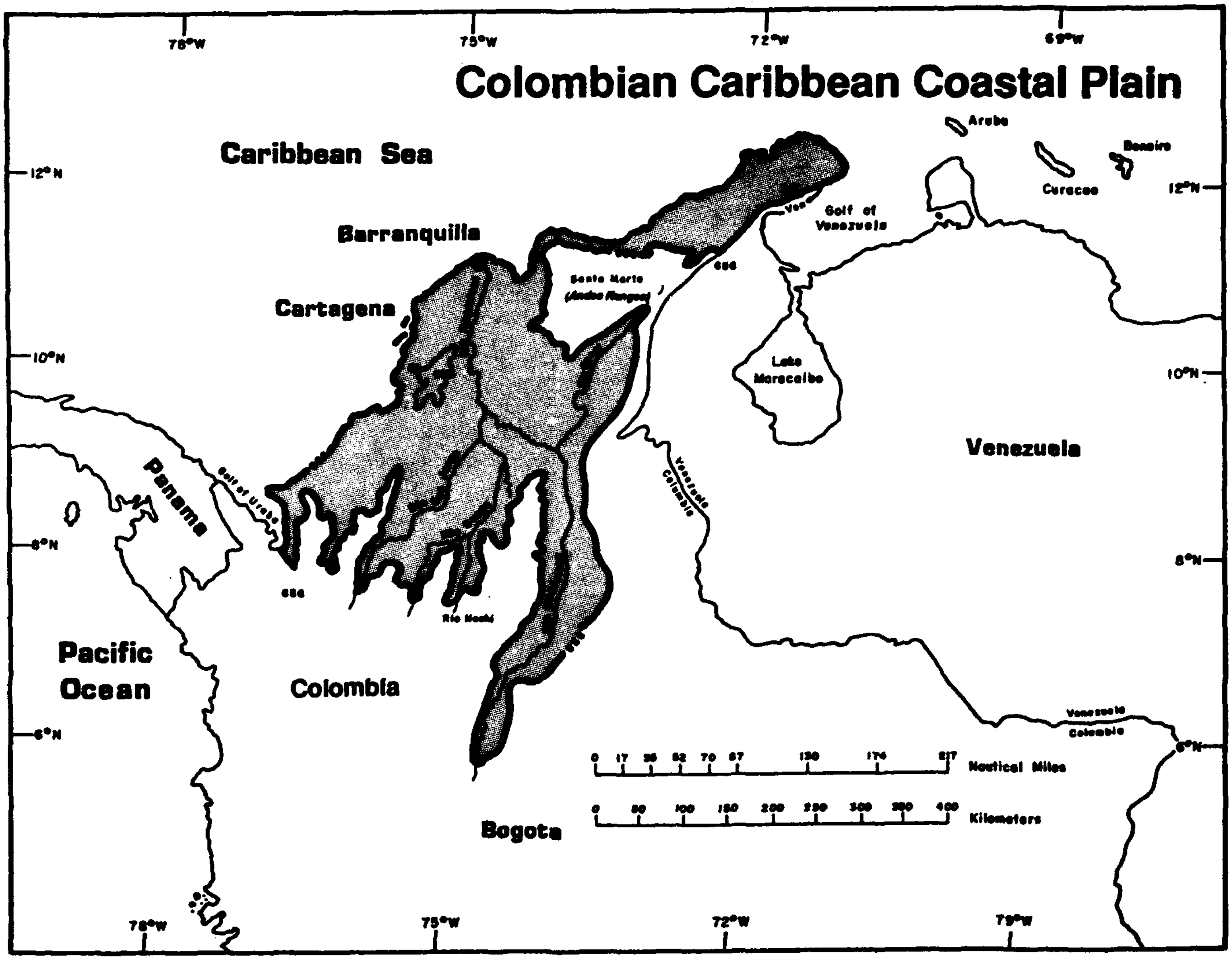


Figure 5-13. The Colombian Caribbean Coastal Plain. This region marks a "zone of transition" from the dry southern Caribbean to the extremely wet parts of Panama and the Pacific Colombian coast. Cloud cover and precipitation gradually increase toward the west, inland from the coast. The Monsoon Trough lies just south of the coast during northern hemisphere summer, occasionally "popping" across Panama into the southern Caribbean and moving the precipitation field northward to the coast.

COLOMBIAN CARIBBEAN COASTAL PLAIN GEOGRAPHY

BOUNDARIES. On the south, the region is bounded by the 656-foot (200-meter) contour line to 8° N, then west to the 656-foot (200 meter) contour line, then along that contour west to the Uraba Gulf (Gulfo de Uraba). It is bounded on the west by the Uraba Gulf, on the north by the Caribbean, and on the east by the Santa Marta Mountains (Sierra de Santa Marta).

TERRAIN. Rolling plains gradually slope upwards toward the 656-foot (200-meter) contour line. Swamps abound near the numerous tributaries of the Cauca and Magdalena rivers, which flood during the rainy season. Swamps also abound along the immediate Caribbean coast in low muddy areas near river mouths, bays, and shallow lagoons.

VEGETATION. Swamps contain dense mangrove forests, where trees reach 150 feet (46 meters). Except in rare clearings, where extremely dense ferns and small mangroves create almost impassable conditions, there is little undergrowth.

Inland of the immediate coast, areas subject to seasonal flooding in and around the Cauca and Magdalena rivers and their tributaries see a combination of evergreen forest, swamp, and floating vegetation. Slightly higher bare ground has deciduous forest with vegetation that favors semi-arid areas. The higher ground between river systems is covered by spiny growth deciduous forest, with maximum heights near 30 feet (9 meters). Cactus is also prevalent.

Immediately east of the Uraba Gulf for about 35 miles (55 km), tropical rain forest extends northward from the western Andes spur to the coast. The rain forest here is two-tiered: the upper tier reaches 100 feet (31 meters), the lower tier only 20 to 50 feet (6 to 15 meters).

GENERAL WEATHER. The Colombian Caribbean coast has two wet seasons and two dry seasons, all linked to the movement of the Monsoon Trough. The major wet season is from mid-August through November, with a secondary in May and June. The major dry season runs from December to April, with a minor secondary in July. The low-level east-to-west jet shown in Figure 5-14 (a year-round phenomenon) is located just onshore along the Colombian Caribbean coast, from the northwest side of the Santa Marta massif to the Gulf of Uraba. The jet induces upwelling immediately offshore in a long, narrow band just off the coast. Because this jet is considerably weaker than the one along the *Venezuelan* Caribbean coast, the upwelling it generates is also weaker. It is still strong enough, however, to further stabilize northeast trade wind air.

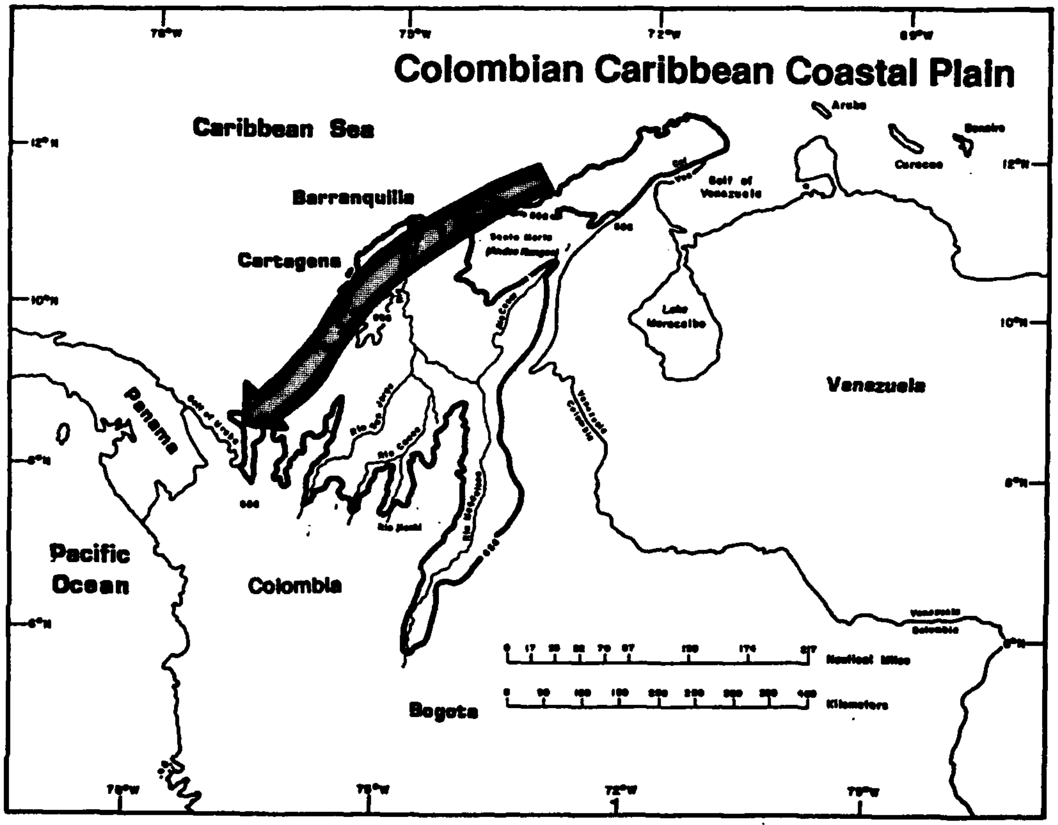


Figure 5-14. Colombian Coastal Low-Level Jet.

SKY COVER. Nights and early mornings see 1-3/10 stratus/stratocumulus, with bases at 400-700 feet (120-215 meters) and tops from 1,500 to 2,000 feet (455 to 610 meters). Stratus dissipates rapidly by 0800 LST, but by 1100 very isolated heavy cumulus forms at 2,500 feet (765 meters) over ridges where forced lift is strong enough to "break through" the subsidence inversion; tops reach 15,000 to 20,000 feet (4.6 to 6.1 km). Isolated showers occur in the afternoon. Figures 5-15 and 5-16 show mean monthly ceiling/visibility below 3,000/7 at Barranquilla and Cartagena, respectively.

With trade wind surges from either hemisphere, lines of heavy cumulus form over the mountains facing the Pacific and are advected over the Caribbean coast. Bases are near 2,500 feet (760 meters) with tops from 20,000 to 40,000 feet (6.1 to 12.2 km).

Visibility (except in precipitation and in early morning along the coast west of the Santa Marta Massif) remains excellent, but may go as low as 1/2 mile for brief periods in precipitation or fog along the coast and in river deltas. Fog banks can form just before and after dawn.

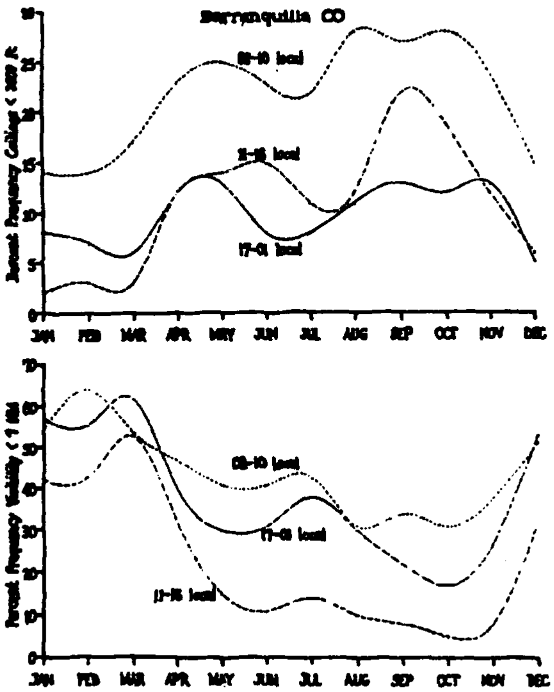


Figure 5-15. Percent Frequency Ceiling/ Visibility < 3,000/7: Barranquilla, Colombia.

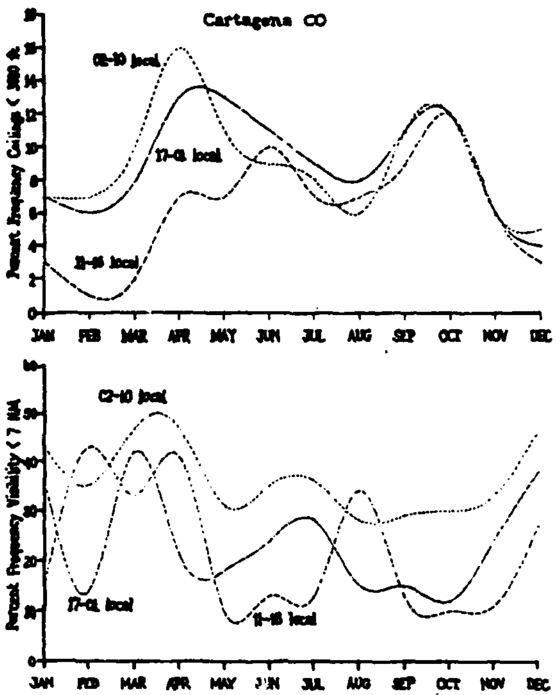


Figure 5-16. Percent Frequency Ceiling/ Visibility < 3,000/7: Cartagena, Colombia.

WINDS. Winds are easterly to northeasterly at 10 to 15 knots. The coastal low-level jet goes through its usual diurnal cycle, with peak winds at 20 to 30 knots near 656 feet (200 meters) just before dawn, returning to near gradient speeds (15 knots) by late morning. Speeds increase again as a surface inversion forms in late evening, and the cycle repeats.

THUNDERSTORMS. Thunderstorms are common during the wet season, and occur about every 4th day. They may build in late afternoon with heating, or may form over higher terrain and move out over the coastal plains during the evening.

PRECIPITATION. Total precipitation in the secondary wet season (May-June) averages about 10 inches (250 mm), but in the major wet season (August-November), rainfall is about 22 inches (550 mm). Total yearly precipitation is close to 35 inches (875 mm). Figure 5-17a shows mean monthly precipitation for the May-June secondary wet season. Figure 5-17b shows mean monthly precipitation for each month in the primary wet season. These charts are drawn from the *WMO Climatic Atlas for South America* and are the most accurate available by far.

TEMPERATURE varies little, ranging from daily highs of 90°F (32°C) to lows near 77°F (24°C). Extremes are 98°F (37°C) and 64°F (18°C).

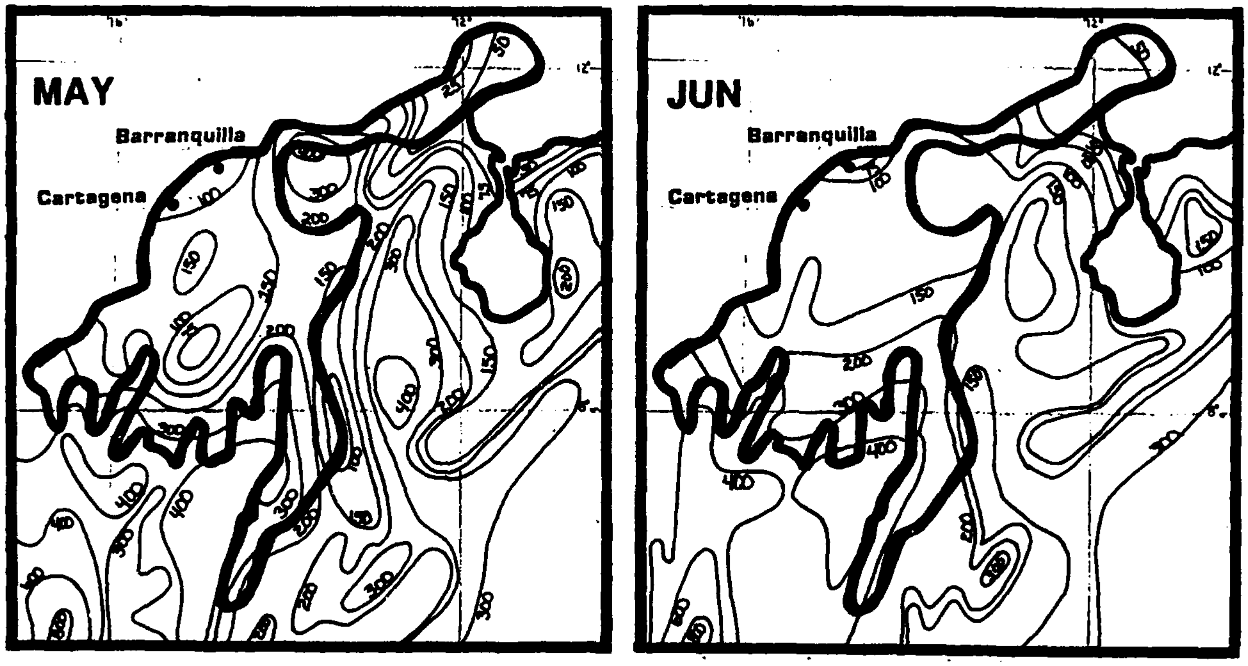


Figure 5-17a. Mean Monthly Precipitation: May & June.

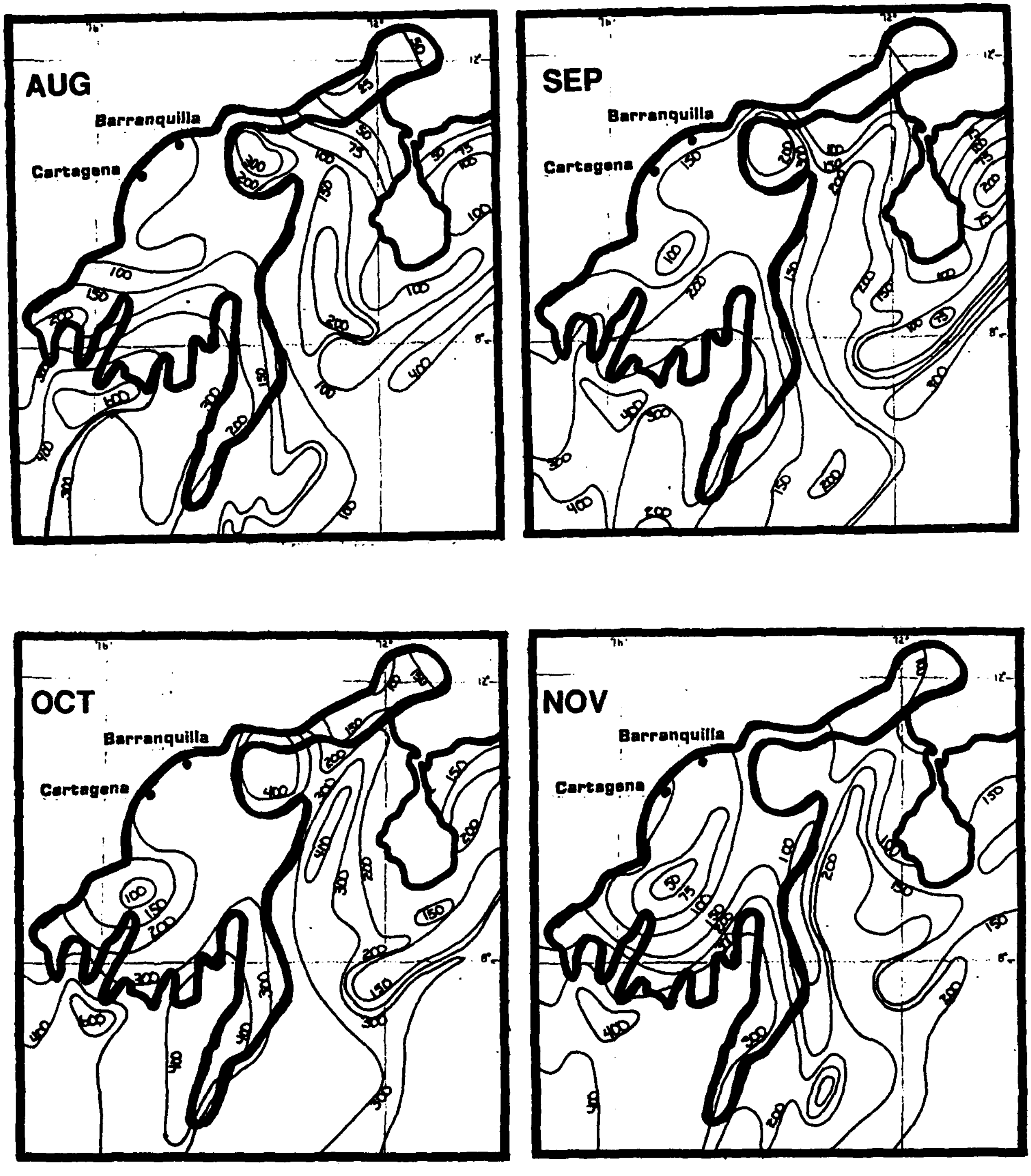


Figure 5-17b. Mean Monthly Precipitation: August-November.

GENERAL WEATHER. Along the immediate coastline, the major (December-April) dry season is extremely dry. Near-desert conditions result from the Monsoon Trough's position in the distant south, with help from the northeast trade wind inversion. A secondary dry season in July results from a temporary southward displacement of the Monsoon Trough and produces only a slight letup in wet season rainfall.

Although very rare, polar incursions can affect the region during the major dry season. From late December through March, very strong North American polar surges can reach the Colombian Caribbean coast, bringing heavy convection and isolated heavy rains. Duration is usually 24 to 36 hours.

Upper-level "cool pools" are also a dry season phenomenon here. They normally originate as cutoff lows in the Gulf of Mexico or western Caribbean, drifting southward from December through March. Satellite imagery shows them as widespread areas of disorganized convection that still move as a unit. An example of a cool pool is shown in Figure 5-18.

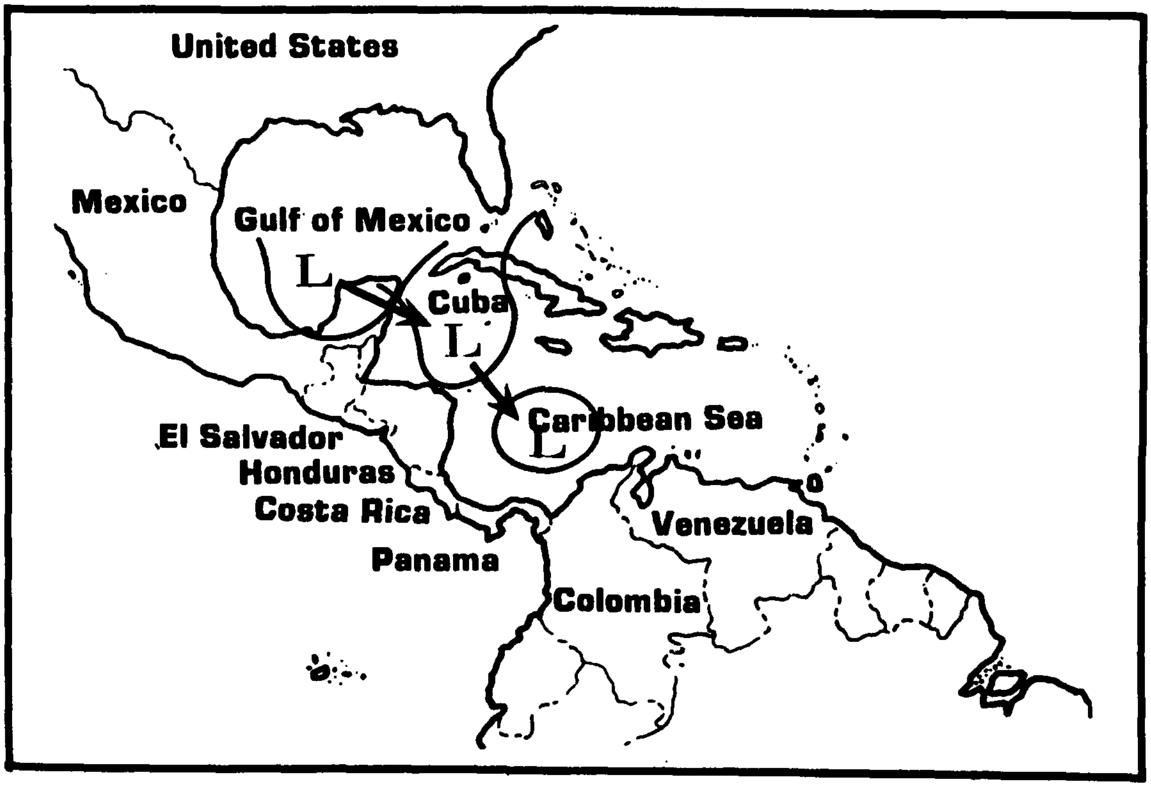


Figure 5-18. Upper-Level "Cool Pool."

SKY COVER. On the Caribbean coast, nights and early mornings see 1-3/10 stratus/stratocumulus with bases at 400-700 feet (120-215 meters), and tops at 1,500-2,000 feet (455 to 610 meters). Stratus dissipates rapidly by 0800 LST. Isolated heavy cumulus forms when the flow has been forced upward to break through the tradewind inversion. (See Figures 5-15 and 5-16 for mean monthly ceiling/visibility frequencies below 3,000/7 at Barranquilla and Cartagena.) With northern hemisphere polar surges, lines of heavy cumulus and isolated cumulonimbus may form just onshore and move southward over ridges, with bases near 2,500 feet (760 meters). Tops range from 20,000 to 40,000 feet (6.1 to 12.2 km). Similar conditions occur with the passage of a "cool pool."

WINDS. Mean winds are east-northeasterly at 10 to 15 knots. Winds behind a northern hemisphere polar surge back to northeasterly and increase to 15-20 knots. The low-level jet shown in Figure 5-14 is strongest during the primary dry season; peak winds at 656 feet (200 meters) reach 25 to 35 knots near dawn, dropping to near gradient speed (25 knots) by mid-afternoon.

THUNDERSTORMS. Thunderstorms occur only over the Andean foothills and the Santa Marta Massif during the primary dry season.

PRECIPITATION. Primary dry season rainfall amounts to only about 3 inches (80 mm), but from January through March the immediate coast gets only a trace. Figure 5-19a shows mean monthly precipitation for each month in the major (December-April) dry season; Figure 5-19b shows mean rainfall for July, the secondary dry season. All charts are from the *WMO Climatic Atlas of South America*, which provides the most accurate data available for this country.

TEMPERATURES. Temperatures vary little. Daily highs are 90°F (32°C), and lows are near 77°F (24°C). Extremes are 98°F (37°C) and 64°F (18°C).

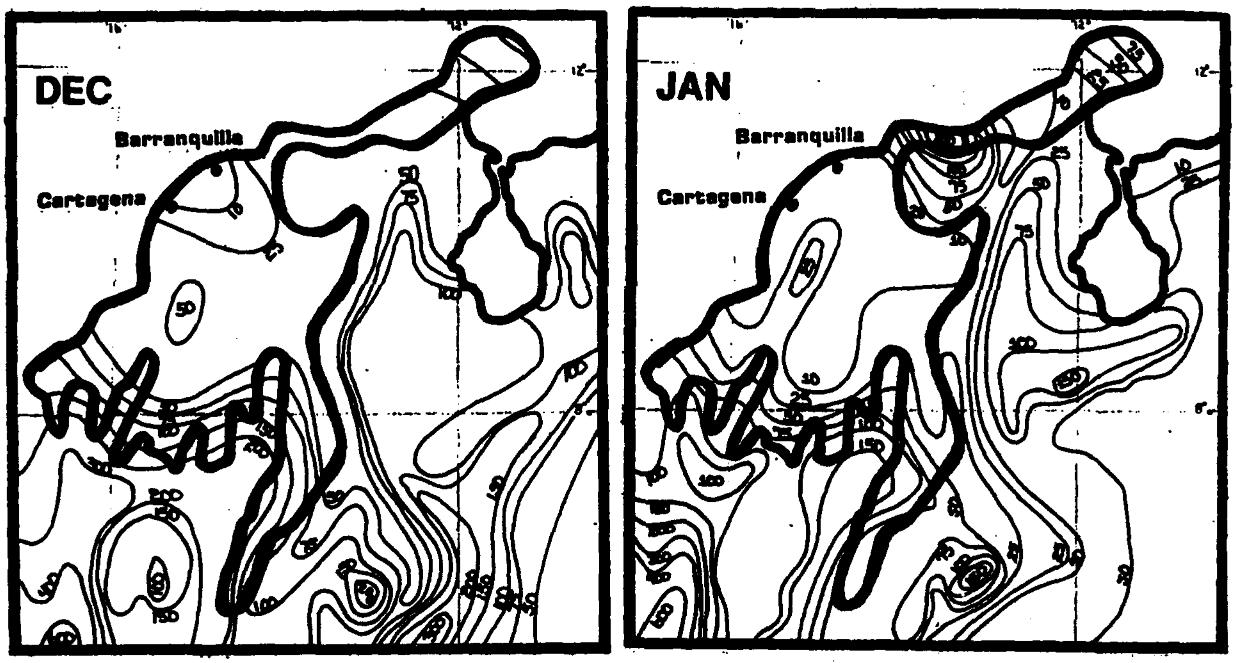


Figure 5-19a. Mean Monthly Precipitation: December & January.

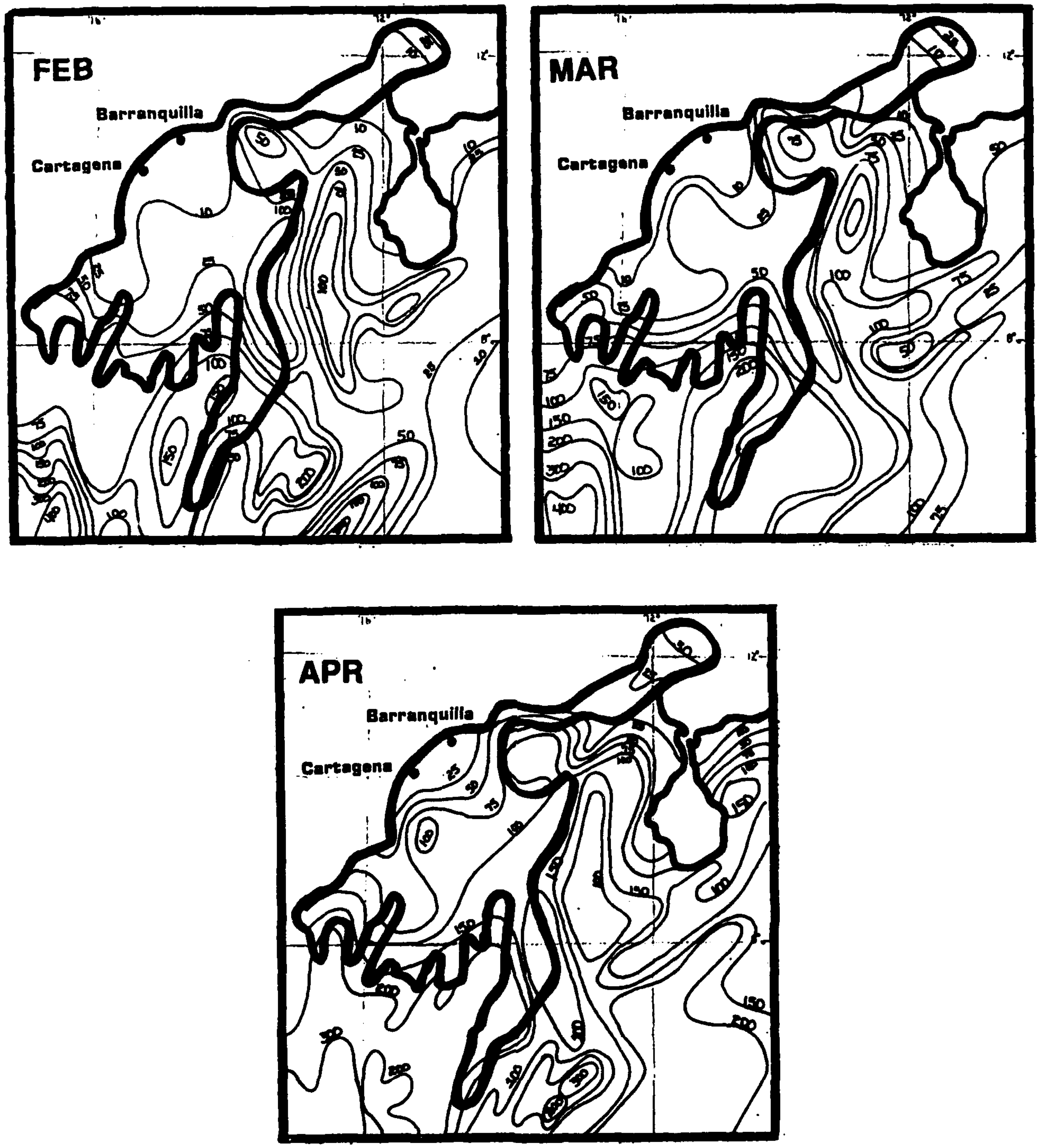


Figure 5-19a, Cont'd. Mean Monthly Precipitation: February-April.

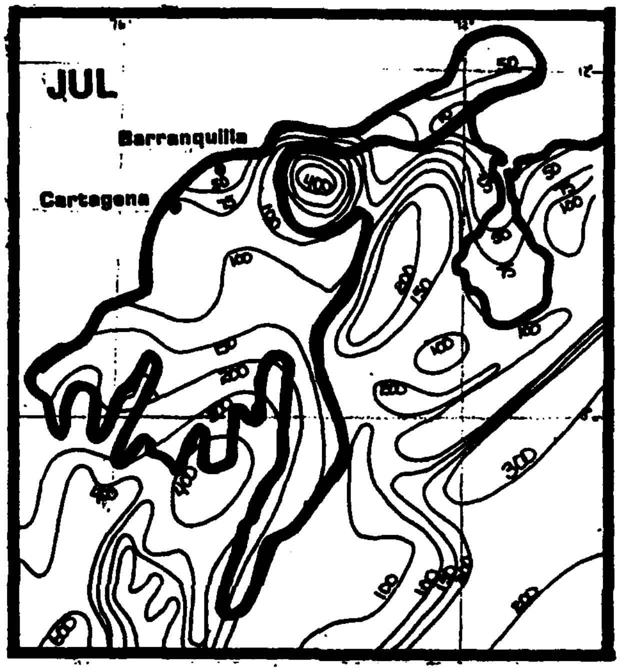


Figure 5-19b. Mean Monthly Precipitation: July.

5.3 THE LAKE MARACAIBO BASIN

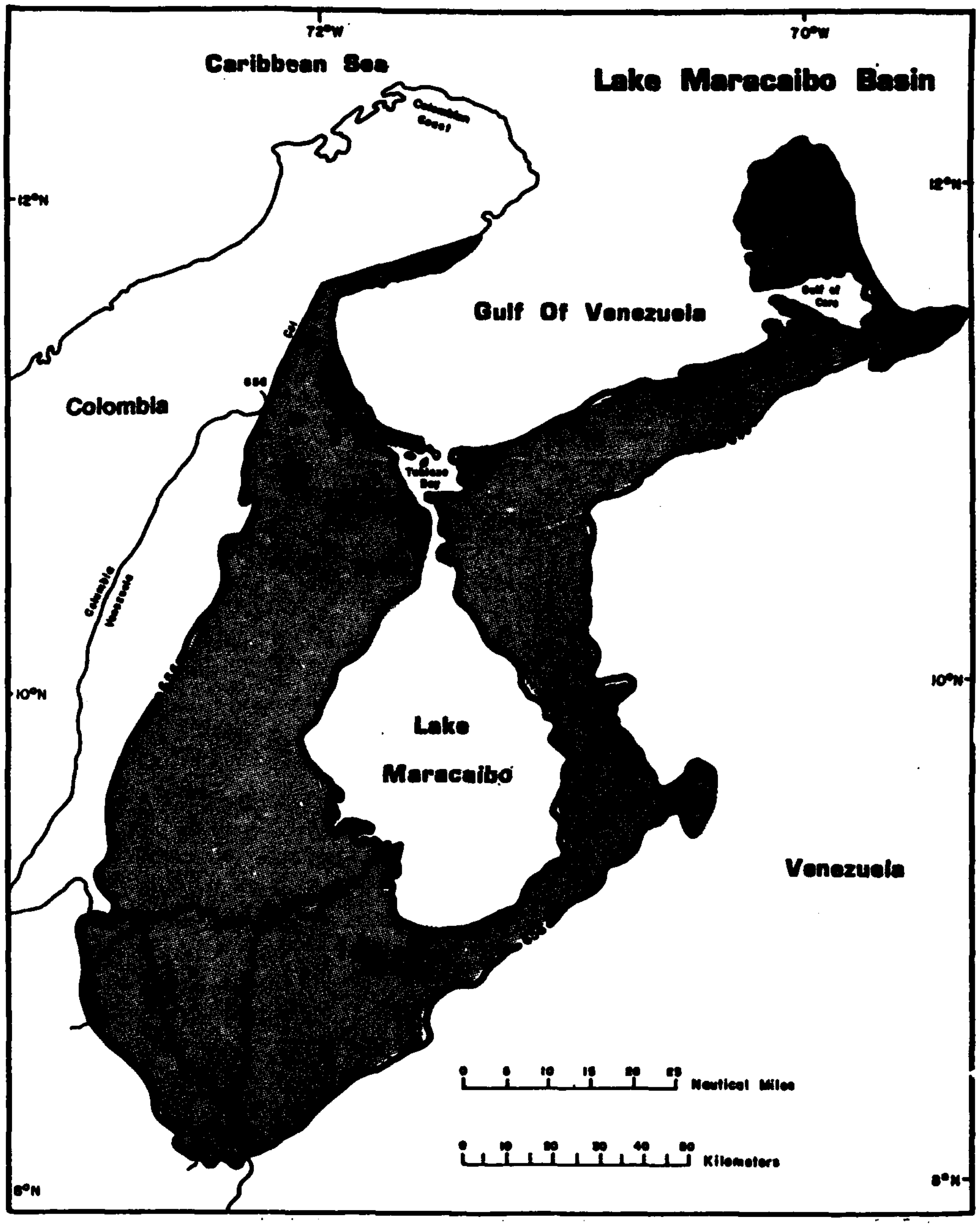


Figure 5-20. Lake Maracaibo Basin. This region encompasses Lake Maracaibo and the plains that surround it. Elevations are below 3,280 feet (1,000 meters). Because of the terrain, this area has its own "mesoscale" climate.

MARACAIBO BASIN GEOGRAPHY

BOUNDARIES. The Maracaibo Basin is bounded on the east, south, and west by the 656-foot (200-meter) contour line, and on the north by the Gulf of Venezuela, which leads to the Caribbean.

TERRAIN. Lake Maracaibo lies in the center of a large basin formed by the splitting of the easternmost Colombia Andean range. The basin is about 230 miles (370 km) long from north to south and 160 miles (255 km) wide from east to west. It is surrounded by mountains on all sides except north. Terrain slopes gradually up to the bases of the mountains. The lake itself, which occupies about a third of the basin's total area, is about 105 miles (170 km) long along its north-south axis, and 60 miles (95 km) across at its widest point. Drainage is through a channel about 5 miles (8 km) wide that leads into the Tablazo Bay and thence into the Gulf of Venezuela, an arm of the Caribbean. Maracaibo City is on the west side of the channel.

VEGETATION. Four distinct types of vegetation are found in the basin. Along the shores of the Gulf of Venezuela, the Tablazo Bay, and just south of the city of Maracaibo, only typical desert vegetation is found, along with a few twisted deciduous trees. The same vegetation is found on the Paraguana Peninsula at the extreme northeast end of the Gulf of Venezuela and over most of the terrain above 3,280 feet (1,000 meters) that extends southward from the Caribbean coast east of Lake Maracaibo as far as Barquisimeto.

A relatively open deciduous forest occupies the plains on both shores of the lake from south of Maracaibo City to about 9° 50' N. The forest dissipates into desert scrub at the northern end of this zone, but transitions into tropical rain forest on the southern end.

On the southwestern side of the lake south of 9° 50' N, deciduous forest gives way to extensive marshland that extends inland toward the southwest for about 35 miles (56 km). Most of this area is covered by 3- to 6-foot (0.9- to 1.8-meter) marsh grass. Isolated clumps of tropical evergreens reach from 10 to 30 feet (3 to 9 meters). Tropical rain forest covers the extreme south and south-southeast shores of the lake and extends inland to the mountains.

CLIMATIC PECULIARITIES. Surrounded as it is on three sides by mountains, and with a narrow opening to the Caribbean on the north, the Maracaibo Basin is a climatological anomaly; although the extreme northern part of the basin belongs in the "Caribbean dry climate" discussed in the "Andean Ranges" section, the extreme southern part lies against the northern slopes of the Venezuelan Andes. Although macroscale controls affect the region, they are overridden by mesoscale and local features for most of the year.

The Monsoon Trough does not normally move northward across the Maracaibo Basin, but strong southern hemisphere cold surges can move it into the Basin during September or October. The wet season here is caused by a clash between the steady northeasterly trades and the mesoscale convergence that results from strong mountain--valley breezes. Conditions can (and do) vary dramatically, depending on the strength of the semipermanent climatic controls.

GENERAL WEATHER. The dry-to-wet transition progresses from south to north, but the effects of the change are most pronounced in the north, where there is a dramatic change from the very dry, semi-arid conditions of the dry season to heavy convective rains. In the southern part of the basin, rainfall increases rapidly from 3 inches (75 mm) a month to 4.9 inches (125 mm). Venezuelans call the wet season their "winter" and the dry season their "summer," even though the calendar says the opposite. Under certain rare conditions, southern hemisphere cold surges can reach to the coast of Venezuela. Figure 5-21 shows how these surges move the convergence zone and Monsoon Trough northward into the extreme southern Caribbean. Such surges also suppress afternoon convection along northern Andean slopes. Although their southeast trajectory results in downslope flow over the Andes and "foehn" effects immediately to the north, the moisture from swamps along the southern end of Lake Maracaibo and the warm lake waters themselves destabilize the air rapidly.

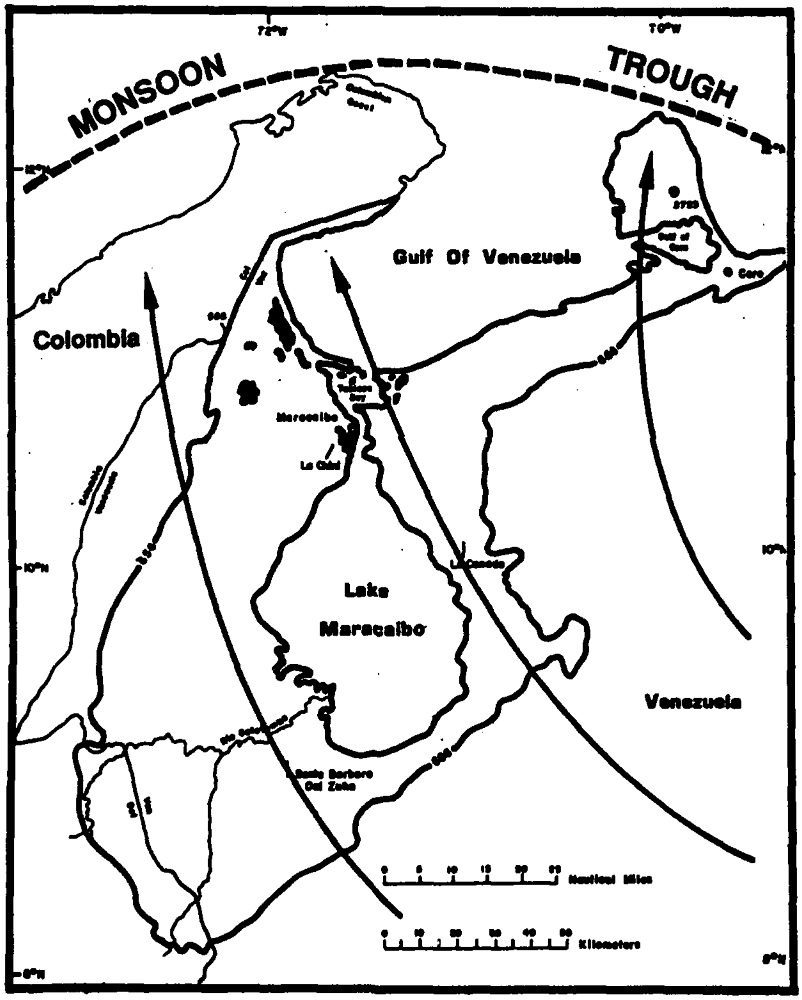


Figure 5-21. "Cold Surge" Effect on Monsoon Trough.

SKY COVER. South of 9° N in the southern Maracaibo Basin, dawn sees patchy coastal stratus decks up to 2,500 feet (765 meters). Fog may or may not form underneath the stratus, depending on wind speeds and precipitation. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus. Isolated heavy cumulus forms over the lake and along the convergence zone; tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 0800 LST, stratus dissipates and heavy cumulus begins to form along the convergence line onshore at 2,000 feet (610 meters). By 1200 LST, the shore areas of the convergence line see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters); tops vary from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered heavy rainshowers fall over immediate inland areas, and isolated heavy cumulus has formed over the lake. Onshore heavy cumulus and showers dissipate after sunset, while lake cumulus continues to build. Lake showers reach their maximum near sunrise. Lake shore and swamp stratus forms after midnight.

North of 9° N in the retreating northeasterly trade winds, patchy low stratus forms near dawn just inland of western shorelines, but dissipates by 0800 LST. Isolated onshore cumulus forms by 1000 LST with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only some very isolated heavy cumulus builds to 15,000 feet (4.6 km) where local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Patchy stratus reforms along the western shoreline just before dawn.

By the end of the transition, heavy cumulus (to include isolated thunderstorms) may form in lines along and just north of the convergence zone in late afternoon and early evening, but they normally dissipate before midnight. By the end of the transition, conditions typical of those south of 9° N have spread northward to 10° 45' N. Maracaibo City ceilings and visibilities, as shown in Figure 5-22, are representative of this region.

WINDS. South of the convergence line, gradient flow changes from north-northeasterly at 10-15 knots to south-southeasterly at 10-15 knots.

THUNDERSTORMS. Thunderstorms appear along the convergence line as it moves northward.

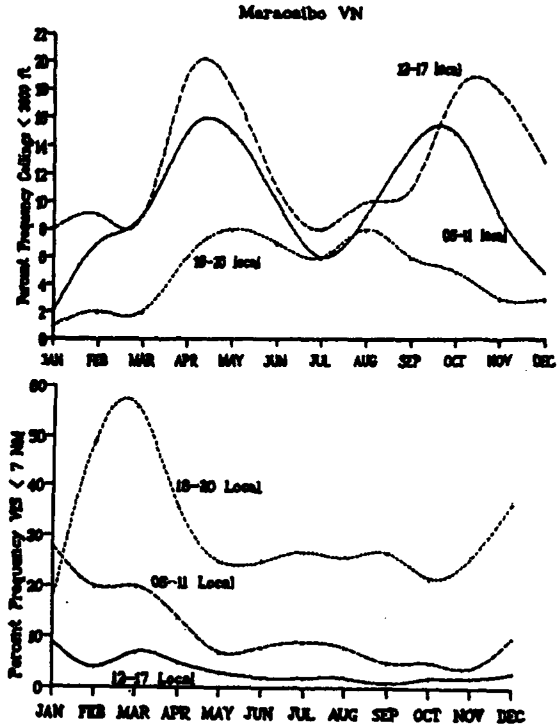


Figure 5-22. Percent Frequency Ceiling and Visibility <3,000/7: Maracaibo City, Venezuela.

PRECIPITATION. Precipitation in southern parts of the basin increases from 3 inches (75 mm) a month to over 4.9 inches (125 mm). In the northern half, there is a dramatic change from the very dry, semi-arid conditions of the dry season to heavy convective rains. Monthly rainfall for Maracaibo City ranges from just over 0.25 inch (6 mm) in the dry season to 1.0 inch (25 mm) at the start of the wet season. North of Maracaibo City, the Caribbean "semi-arid zone" continues to hold precipitation to less than 0.25 inch (6 mm).

TEMPERATURE. Highs range from 88 to 92° F (31 to 33° C), lows from 75 to 79°F (23 to 25°C). The record high of 98°F (37°C) was recorded just before the onset of the wet season.

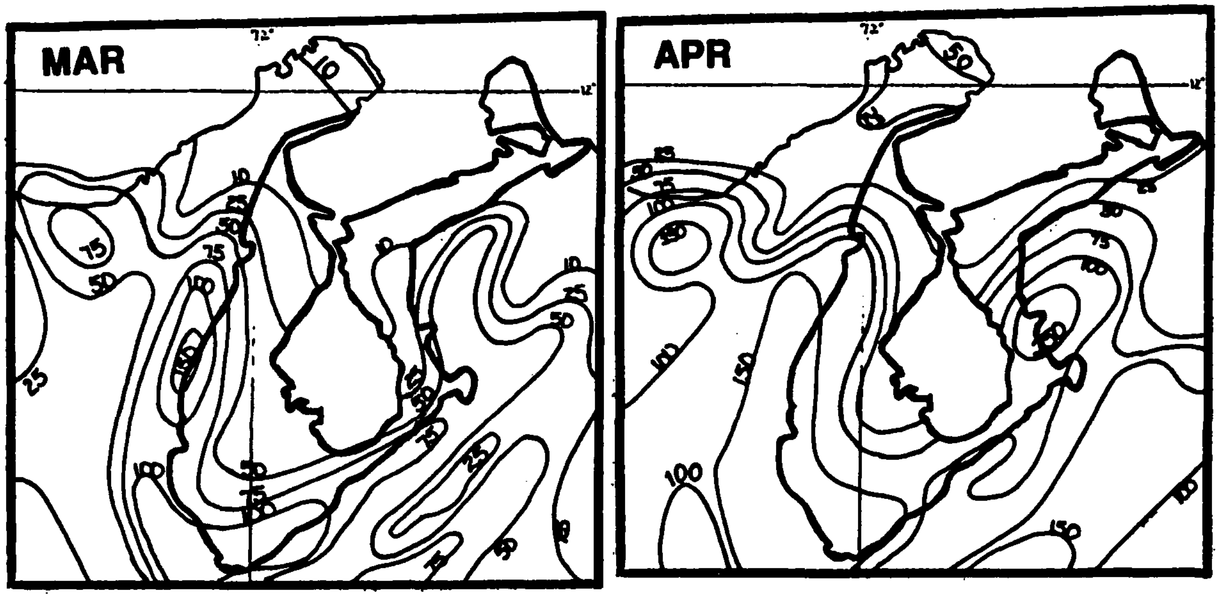


Figure 5-23. Mean Monthly Precipitation: March-April.

GENERAL WEATHER. In September and early October, southern hemisphere cold surges and the slowly weakening northeasterly trade winds combine to move the Monsoon Trough temporarily as far north as 11° 45' These surges account for an October precipitation maximum. Normally, equatorial regions have two precipitation and cloud cover maximums, one corresponding to Monsoon Trough passage poleward, and the other with its passage equatorward. In the Maracaibo Basin, the initial strengthening of the trades in April results in a secondary maximum. Once the trades reach full strength, cloud cover and precipitation decrease slightly.

Under normal conditions, strong southern hemisphere polar surges occasionally penetrate the Maracaibo Basin in September and early October. Very rarely, usually in July or August, an exceptionally strong surge moves all the way into the southern Caribbean. The typical frontal positions shown in Figure 5-24 demonstrate the continuity of such outbreaks as they move northward through South America. Venezuelan meteorologists state that these occurrences, while uncommon, occur more often than is generally believed.

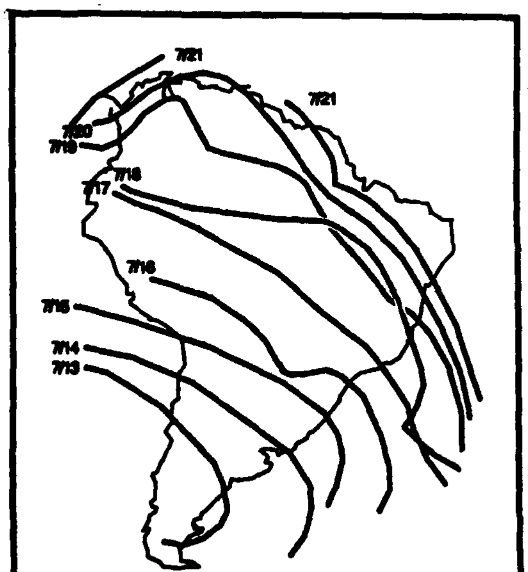


Figure 5-24. "Cold Surge" Continuity: 13-21 July 1975.

SKY COVER. North of 11° N in the northeasterly trade winds, patchy low stratus forms near dawn just inland of western shorelines, dissipating by 0800 LST. Isolated onshore cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence overcomes the subsidence inversion. Clouds clear rapidly after sunset. Patchy stratus reforms along the western shoreline just before dawn.

South of 11° N, dawn sees patchy coastal stratus decks up to 2,500 feet (765 meters). Fog may or may not occur underneath the stratus, depending on wind speed and precipitation. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus, altostratus or cirrostratus. Isolated heavy cumulus occurs over the lake and along the convergence zone; tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 0800 LST, the stratus has dissipated and heavy cumulus begins to form along the convergence line onshore from Lake Maracaibo at 2,000 feet (610 meters). By 1200 LST, the shore areas of the convergence line see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered heavy rain showers occur over immediate inland areas, and isolated heavy cumulus has formed over the lake. Onshore heavy cumulus and showers dissipate after sunset, but lake cumulus continues to build. Lake showers reach their maximum near sunrise. Lakeshore and swamp stratus forms after midnight.

By the end of the wet season, in late afternoon and early evening, heavy cumulus (including isolated thunderstorms) can form in lines along and just north of the convergence zone. Although line formation is most common just ahead of southern hemisphere cold surges, the lines normally dissipate before midnight.

WINDS. Gradient flow south of the convergence line changes from north-northeasterly at 10 to 15 knots to south-southeasterly at 10 to 15 knots.

THUNDERSTORMS are most common along the convergence line and with southern hemisphere cold surges.

PRECIPITATION. North of Maracaibo in the Caribbean "semiarid zone," monthly precipitation is less than 0.25 inch (6 mm). But from Maracaibo south to the convergence zone, annual rainfall averages just over 25.5 inches (650 mm). At the southern end of the lake and on northern Andean slopes, annual rainfall ranges from 27.5 to 35 inches (700 to 900 mm). Figure 5-25 gives mean monthly precipitation for each full month of the Maracaibo Basin wet season.

TEMPERATURE. Highs range from 88 to 92°F (31° to 33°C); lows, from 75 to 79°F (23° to 25°C). Temperatures associated with southern hemisphere "cold surges" at the end of the wet season have exceeded 100°F (38°C).

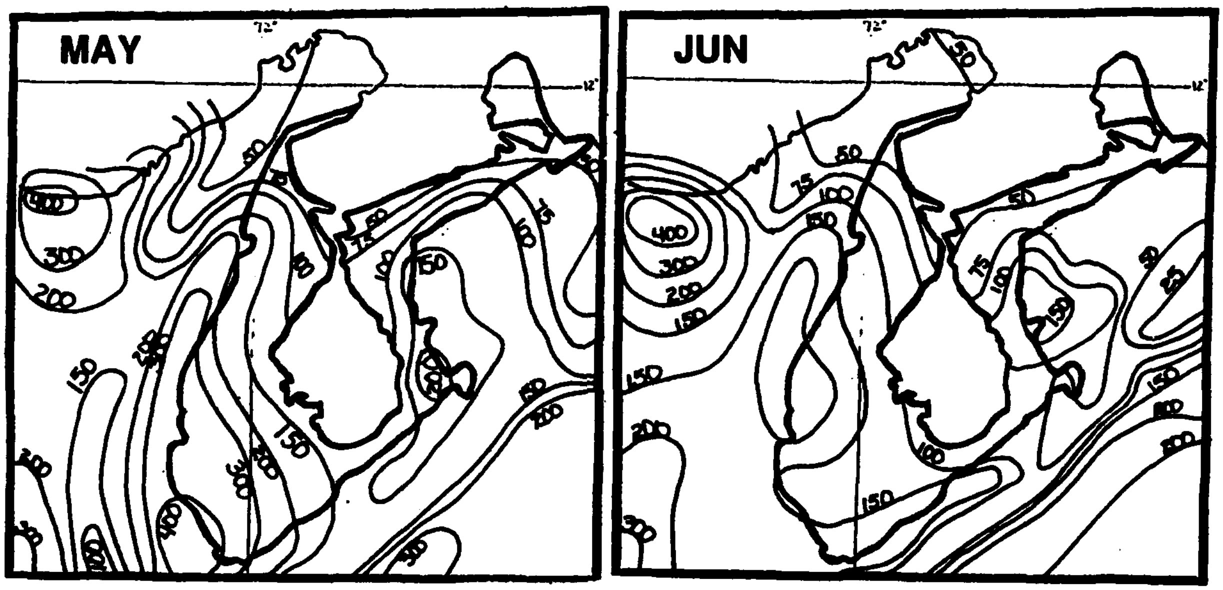


Figure 5-25. Mean Monthly Precipitation: May-June.

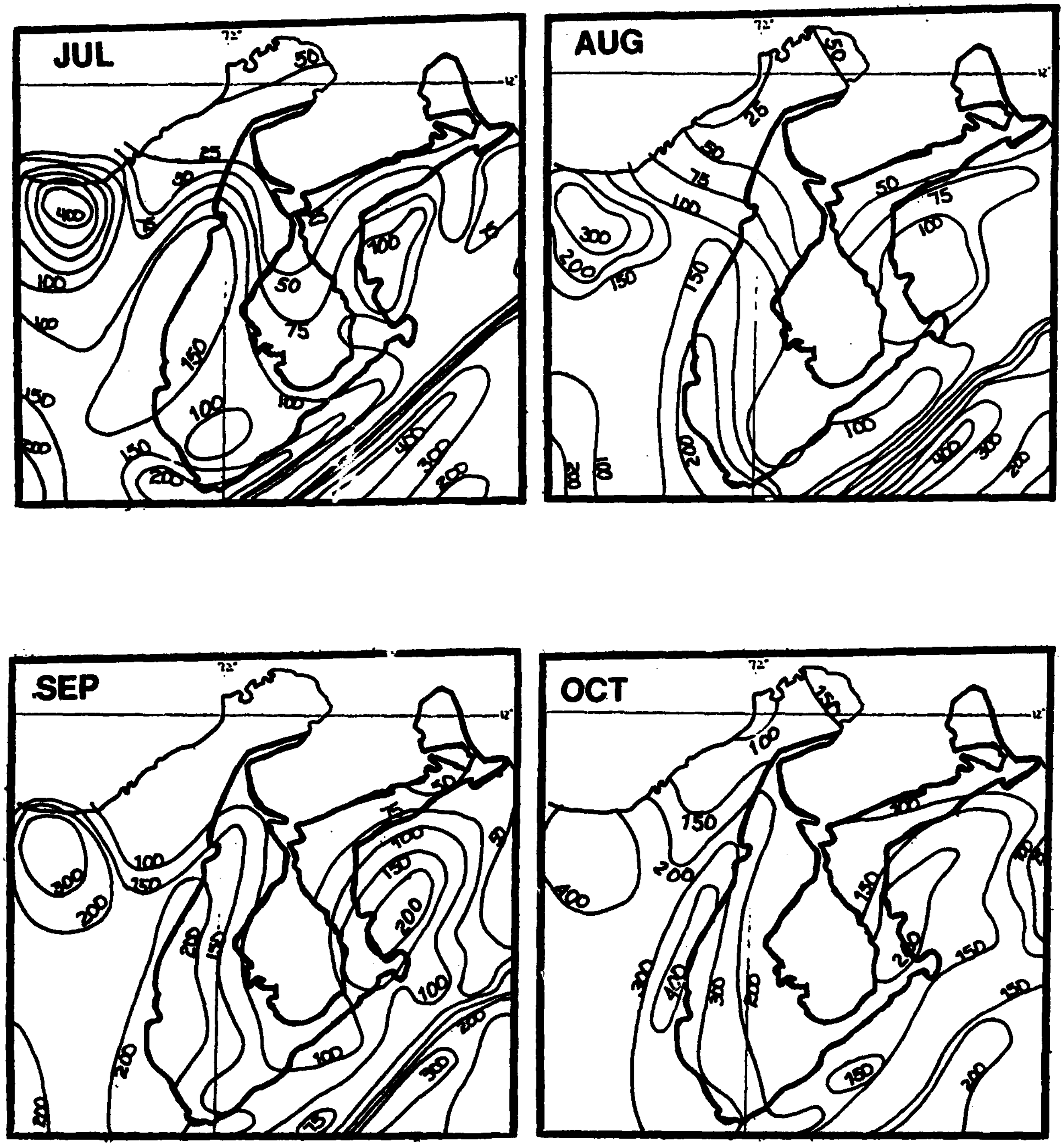


Figure 5-25, Cont'd. Mean Monthly Precipitation: July-October.

GENERAL WEATHER. The transition from the wet to the dry season, usually in mid- to late November, is a rapid one. It progresses from north to south, but is more marked in the north, where rainfall decreases rapidly from 3 inches (77 mm) a month to just under 0.5 inch (12 mm). In the south, the change is more gradual, with the heavy convective rains becoming widely scattered showers. The northeast trades stabilize and increase in intensity over the Maracaibo Basin as the Monsoon Trough moves into the southern Amazon Basin. The strengthening subsidence inversion combines with a weakened, more southward position of the Lake Maracaibo convergence zone (which see under "Mesoscale and Local Features") to provide a "lid" that caps most convection except that in the immediate area of the convergence zone. Figure 5-26 shows the northeast trade wind flow behind the southward-displaced convergence zone.

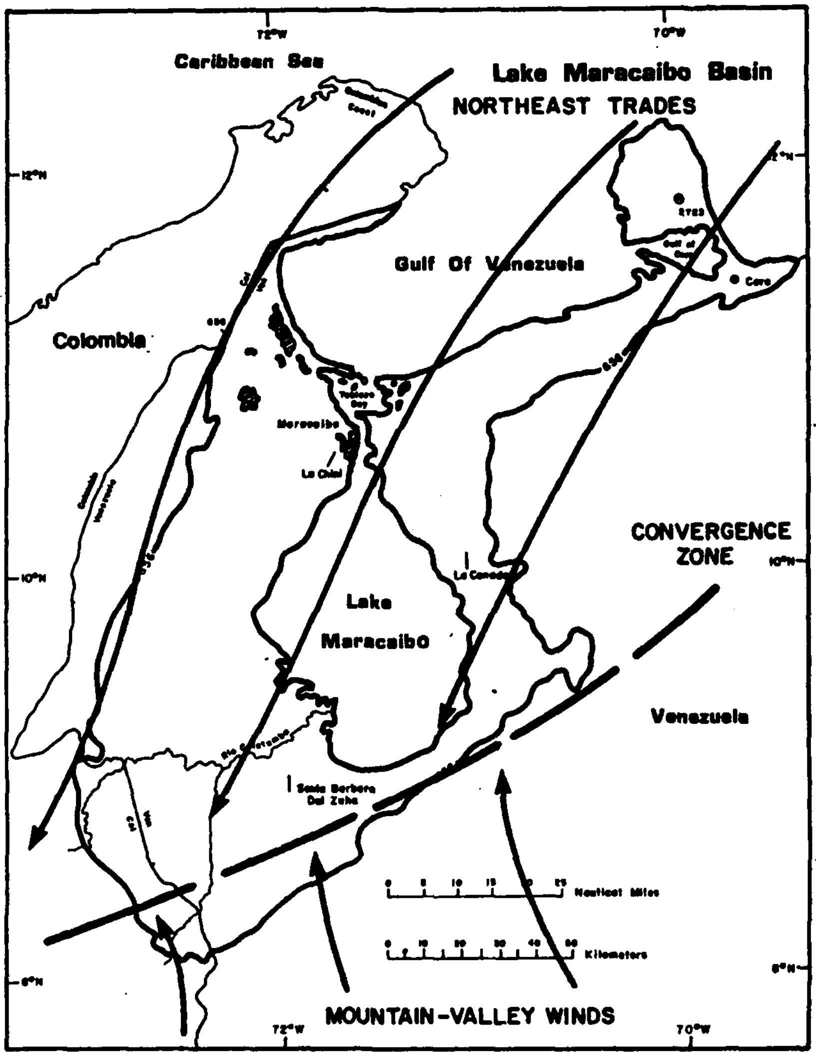


Figure 5-26. Northeast Trade Wind Flow.

SKY COVER. North of 11° N in the advancing northeasterly trade winds, patchy low stratus forms near dawn just inland of western shorelines, but dissipates by 0800 LST. Isolated onshore cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) where local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Patchy stratus reforms along the western shoreline just before dawn.

South of 11° N, patchy coastal stratus decks form, with bases from 500-1,000 feet (150-305 meters) to 2,500 feet (765 meters), but dissipate by 0800 LST. Fog may or may not form under the stratus, depending on wind speed and precipitation. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus/ altostratus or cirrostratus. Isolated heavy cumulus or cumulonimbus occurs over the lake and along the convergence zone. Tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). Heavy cumulus begins to form along the convergence line onshore from Lake Maracaibo at 2,000 feet (610 meters). By 1200 LST the shore areas of the convergence line see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters). Tops vary from 15,000 to 40,000 feet (4.6 to 12.2 kilometers). By 1400 LST, scattered heavy rain showers occur over the immediate inland areas; isolated heavy cumulus has formed over the lake. Onshore heavy cumulus and showers dissipate after sunset, but lake cumulus continues to build. Lake showers reach their maximum near sunrise. Lakeshore and swamp stratus forms after midnight. See Figure 5-27 for Maracaibo mean ceiling and visibility frequencies.

By the end of the November transition, conditions typical of those north of 11° N have spread south to 9° N. Heavy cumulus forms in lines along and just north of the convergence zone in late afternoon and early evening, normally dissipating before midnight.

WINDS. General gradient flow north of the convergence line changes from south-southeasterly at 10 to 15 knots to north-northeasterly at 10 to 15 knots

THUNDERSTORMS. Thunderstorms appear along the convergence line as it moves northward.

PRECIPITATION. North of Maracaibo City, the Caribbean "semiarid zone" continues to hold precipitation to less than 0.25 inch (6 mm) a month. The northern half has a dramatic decrease from 3 inches (77 mm) at the end of the wet season to 0.5 inches (12 mm) at the start of the dry season. Precipitation in the southern portion of the region decreases from an average of almost 8 inches (200 mm) a month in the wet season to near 4.9 inches (125 mm) a month in the dry. Figure 5-27 shows mean November precipitation.

TEMPERATURE. Highs are from 88 to 92°F (31° to 33°C); lows from 75 to 79°F (23° to 25°C).

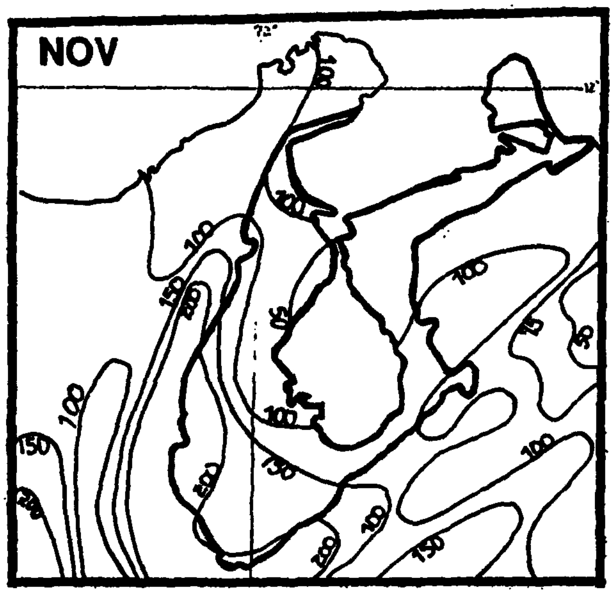


Figure 5-27. Mean Precipitation: November.

GENERAL WEATHER. Except for the immediate northern and eastern Andes slopes (where precipitation continues due to upslope flow), the Maracaibo Basin dry season begins in late November and lasts until early April. Some locations north of Maracaibo receive only a trace (1 mm) of rainfall in their driest month.

SKY COVER. North of 9° N in the advancing northeasterly trade winds, patchy low stratus forms near dawn just inland of western shorelines, but dissipates by 0800 LST. Isolated onshore cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters); only very isolated heavy cumulus builds to 15,000 feet (4.6 kilometers) where local heating and or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Patchy stratus reforms along the western shoreline just before dawn.

South of 9° N, along the western and southern shores of Lake Maracaibo inland to the Andes, dawn sees patchy coastal stratus decks up to 2,500 feet (765 meters) that dissipate by 0800 LST. Fog may or may not occur under the stratus depending on wind speed and precipitation. Above 2,500 feet (765 meters) skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus. Isolated heavy cumulus forms over the lake and along the convergence zone; tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). Heavy cumulus begins to form along the convergence line onshore from Lake Maracaibo at 2,000 feet (610 meters). By 1200 LST, the shore areas of the convergence line- see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered heavy rain showers fall over immediate inland areas, and isolated heavy cumulus has formed over the lake. Onshore, heavy cumulus and showers dissipate after sunset, but lake cumulus continues to build; lake showers reach their maximum near sunrise. Lakeshore and swamp stratus forms after midnight. Isolated heavy cumulus may form in lines along and just north of the convergence zone in late afternoon and early evening, normally dissipating before midnight.

WINDS. North of the convergence zone, gradient flow is north-northeasterly at 10 to 15 knots; south of the zone, flow is southerly at 5 knots.

THUNDERSTORMS. Very isolated thunderstorms occasionally appear along and just inland of the convergence zone.

PRECIPITATION. Dry season precipitation averages slightly more than 1.2 inches (35 mm), except for the southern and western shores, where seasonal rainfall, especially in the Andean foothills, can be as much as 13.75 inches (350 mm). Mean December, January, and February precipitation is shown in Figure 5-28.

TEMPERATURE. Highs are from 86 to 90°F (30° to 31°C); lows from 72 to 75°F (21° to 23°C). Temperatures at height of the dry season, however, have exceeded 95°F (35°C).

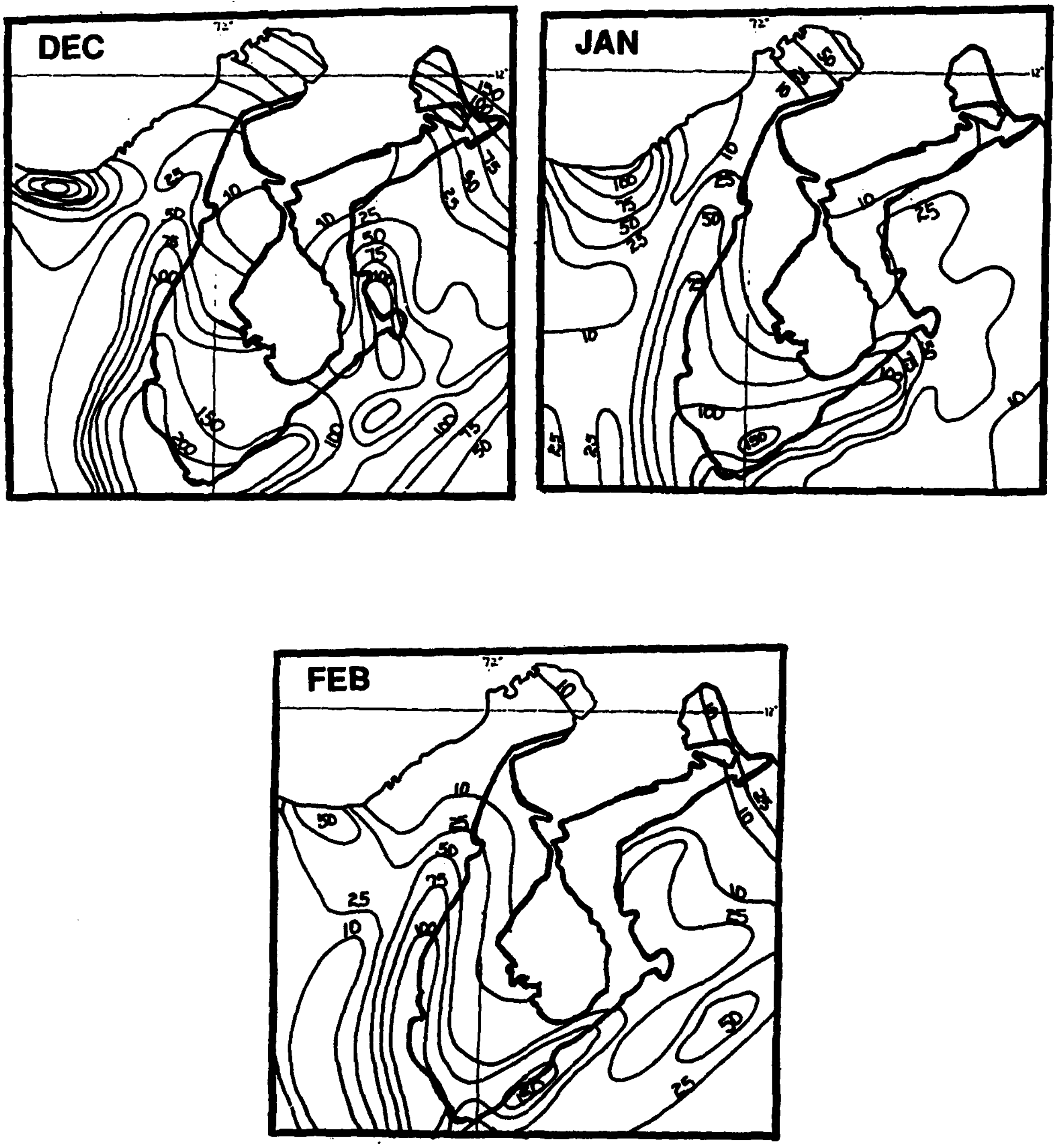


Figure 5-28. Mean Monthly Precipitation: December, January, February.

5.4 THE ANDES RANGES

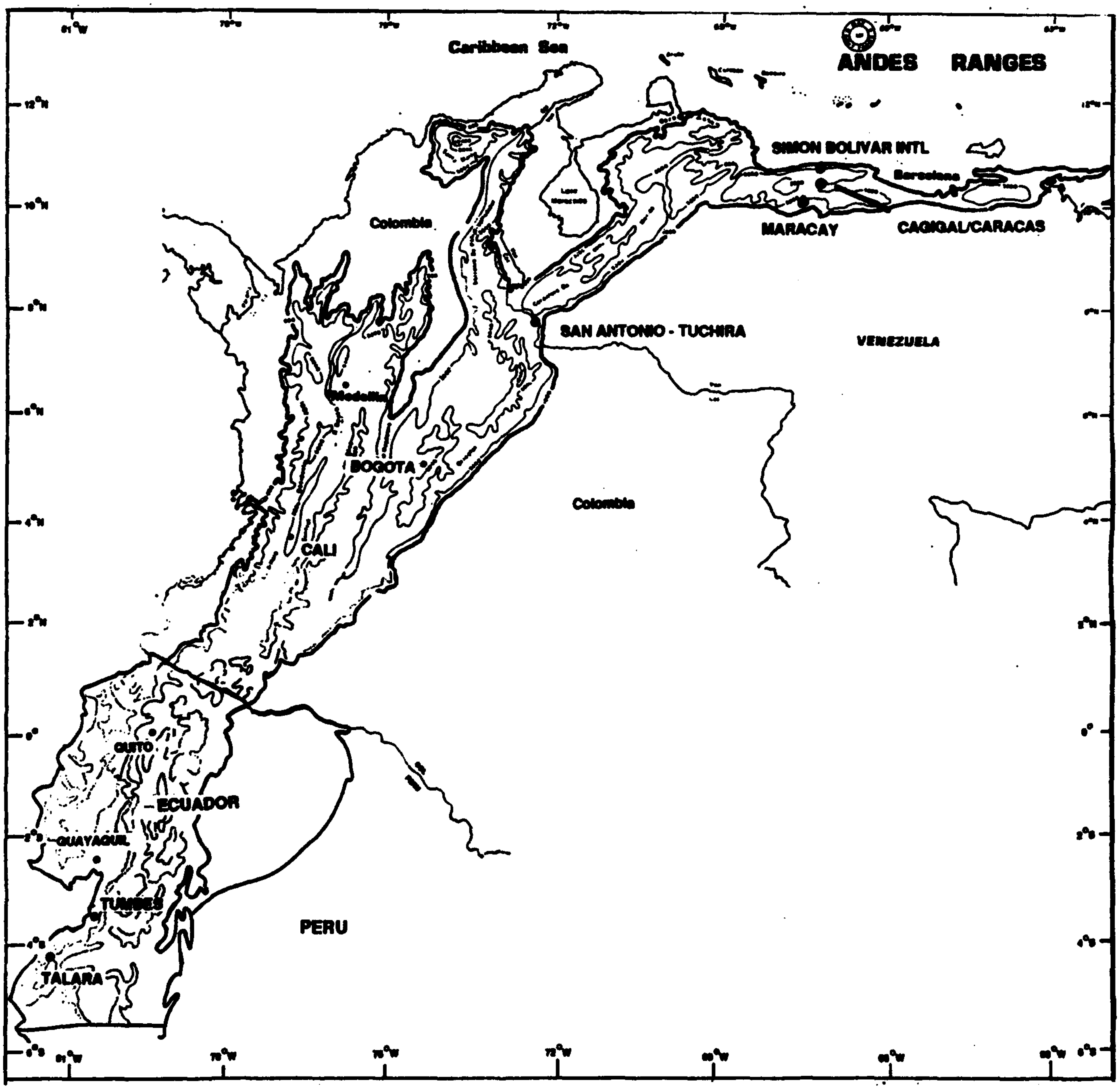


Figure 5-29. The Andes Ranges. These massive mountain ranges lie from 100 to 200 miles (160 to 320 km) inland, paralleling the Pacific Coast from Ecuador into Central Colombia. They consist of two to three parallel primary ranges separated by deep river valleys.

ANDES RANGES GEOGRAPHY

GENERAL. Comprising from one to three main ranges, the Andes chain acts as a major climatic divider between the Amazon-Orinoco Basins and the Pacific Coast. The mean crest elevation from Ecuador into northern Colombia is between 11,000 and 14,400 feet (2.8 and 4 km); highest elevations are just over 20,000 feet (6.1 km). These ranges effectively split the South American lower troposphere into two parts: one directly influenced or controlled by the Atlantic, the other directly influenced or controlled by the Pacific. The Monsoon Trough, except on those rare occasions when it moves north into the Caribbean, is effectively divided into two parts: an Amazon-Orinoco Basin trough and a Pacific Ocean trough. The Amazon-Orinoco Basin portion moves with the Atlantic Ocean trough, but the Pacific Ocean part moves independently. Finally, the Andes Ranges act as an elevated heat source, analogous to, but on a much smaller scale than, the Himalayas. This phenomenon is reinforced by high-level subsidence over the Andes, caused by the massive convection occurring over the Pacific coast and Amazon/Orinoco basins.

BOUNDARIES. The boundaries chosen to describe the perimeters of the Andes Ranges region are extremely complex. The region is bounded:

On the south: by 5° S (the Ecuador-Peru border).

On the west: by the Pacific Coast in Ecuador; elsewhere, by the 656-foot (200-meter) contour line.

On the north: In Colombia, by the 656-foot (200-meter) contour line from the Panama border along the Caribbean to the border of Venezuela. In Venezuela, by the 656-foot (200-meter) contour around Lake Maracaibo to Coro (11° 25' N, 69° 41' W) on the Caribbean side of the easternmost Andes Range, thence from the Caribbean eastward to the tip of the Paria Peninsula.

On the east: By the 3,280-foot (1,000-meter) contour line at the Maranon River sloping down to the 1,000-foot (328-meter) contour line at the Venezuela-Colombia border, thence eastward along the south side of the easternmost Venezuelan Andes range, gradually sloping down to the 656-foot (200-meter) contour on the south side of the Paria Peninsula in extreme northeastern Venezuela.

TERRAIN. The following discussions of terrain in the Andes proceed from south to north.

In Ecuador, a single main range runs from the Peruvian border north to central Ecuador (2° S) where it separates into two ranges (split by various river valleys) that continue northward into southern Colombia. Mean elevations average 13,520 feet to 20,280 feet (4,120 to 6,180 meters). Chimborazo, the highest peak, is 21,327 feet (6,500 meters). Many peaks are of volcanic origin. A few are active, but most are dormant. The permanent snow line is near 15,000 feet (4,570 meters). Elevations in Ecuador are suspect because thorough mapping has yet to be completed. Most streams flowing in the inter-range valley eventually make their way through gaps in the eastern range to flow into rivers that join the Amazon system in eastern Peru. Numerous small rivers flow into the Pacific. One major Andes spur curves southwestward from the western Andes range near 00° 20' S to terminate in the Clay Hills (Colonche de Cerros) at 2° 45' S. The maximum elevation of this range is 3,500 feet (1,070 meters) near 2° S, 80° 20' W. The Clay Hills and the main western Andes range define the Daule-Babahayo River (Rios de Daule y Babahayo) system that drains into the Gulf of Guayaquil (Gulfo de Guayaquil).

The Main Andes Ranges are oriented north-northeast to south-southwest from the Peru-Equador border through Colombia and into Venezuela, where an extension of the easternmost range turns eastward to run just south of the Caribbean coast, eventually ending in the Paria Peninsula opposite Port of Spain, Trinidad. Ranges throughout Ecuador and Colombia are characterized by steep terrain gradients and numerous mountain-valley systems. Pronounced leeside rain-shadow effects are found throughout the main ranges.

In Colombia, the eastern Andes range splits in two near 2° N, 115 miles (185 km) north-northeast of the Equador-Colombia border. From this point, three main ranges (Cordillera Occidental, Cordillera Central, and Cordillera Oriental) run north-northeastward. Two major rivers flow northward between these ranges and into the Caribbean.

Two Degrees North--the start of the Cordillera Central-Cordillera Oriental ranges--also marks the headwaters of one of the two major Colombian Andes rivers, the Rio Magdalena. The headwaters of the other primary Colombian Andes river, the Cuaca, are almost immediately west of the Magdalena headwaters, between the Cordillera Central and the Cordillera Occidental. Both flow north-northeastward for 500 miles (800 km) to separate the three ranges. The Cauca then joins the Magdalena in the Caribbean coastal plains at 9° N, near the town of Magangue. The combined streams empty into the Caribbean at Barranquilla.

The Western Mountains (Cordillera Occidental). Elevations here average 6,000-10,000 feet (1,830-3,050 meters). Highest elevations are between 4° 30' N and 5° 10' N, where the highest peak reaches 15,320 feet (4,670 meters).

The Central Mountains (Cordillera Central). Elevations average 10,000-15,000 feet (3,050-4,575 meters). The Cordillera Central is the "spine" of the Andes ranges. Maximum known elevation is 18,865 feet (5,751 meters) at 3° N 76° W.

The Eastern Mountains (Cordillera Oriental). This range trends north- northeastward from its origin at 2° N toward the Venezuelan border. Heights average 8,000-14,000 feet (2,440-4,270 meters). Highest known elevation is 18,100 feet (5,520 meters) at 6° 40' N, 72° 20' W. The permanent snow line is between 15,500 and 16,000 feet (4,725 to 4,875 meters). The range reaches the Venezuelan border at 7° 30' N, where it splits to enclose the Lake Maracaibo Basin, which see. The western range, the Perija-Valledupar mountains (Serrania de Perija-Valledupar), forms the Venezuela-Colombia border north of 9° 10' N to its termination 120 miles (190 km) west of the Gulf of Venezuela (Gulfo de Venezuela), at 11° 10' N, 72° 10' W. Elevations here average 6,000-10,000 feet (1,830-3,050 meters). Highest known elevation is 12,100 feet (3,690 meters) at 10° 20' N, 72° 55' W.

At 7° 10' N, the Cordillera Occidental and Cordillera Central join to become one range; heights drop rapidly to less than 10,000 feet (3,050 meters) as the combined range continues north towards the Caribbean to end near 8° 50' N. The permanent snow line is from 15,500 to 16,000 feet (4,725 to 4,875 meters)

The Santa Marta Massif (Sierra Nevada de Santa Marta). This isolated mountain massif lies along the Caribbean coast between Santa Marta and the Valledupar Mountains. Actually a westward continuation of the Valledupar range, this triangularly shaped block is bounded by the points 11° 10' N, 72° 35' W; 10° 4' N, 73° 54' W; and 11° 19' N, 74° 13' W. Elevations average 4,000-13,000 feet (1,220-3,960 meters). Highest known elevation is 18,947 feet (5,775 meters). The permanent snow line here is about 16,500 feet (5,030 meters).

In Central Colombia, the easternmost range curves northeast to just south of Lake Maracaibo in southwestern Venezuela where it splits into two ranges. One runs almost straight north just west of Lake Maracaibo to the western Venezuelan coast. The other curves eastward along the central Venezuelan coast, ending just northwest of the Orinoco River delta. Elevations here are above 3,280 feet (1,000 meters). The highest peaks--mostly volcanic--are in Ecuador and Colombia. They range from 17,000 to 22,000 feet (5,180 to 6,705 meters). Vegetation on lower slopes varies from tropical rain forest in eastern Ecuador and southeastern Colombia (and again on the Pacific sides in Ecuador and Colombia) to tropical savannah in northeastern Colombia and on the southern slopes in Venezuela. In the higher elevations, temperate forests become Alpine scrub. Peaks above 14,500 to 16,000 feet (4,420 to 4,875 meters), depending upon location, have permanent snow fields.

In Venezuela, the Andes range enters near 7° 30' N, just southwest of San Cristobal. The highest portions of the range run from this point northeastward to 10° N, where the orientation changes to east-west, ending some 400 miles (640 km) east, in the Paria Peninsula.

The Merida Mountains (Cordillera de Merida), located between San Cristobal and Barquisimeto (10° 05' N, 65° 20' W), contain the highest peaks in the Venezuelan Andes. Average elevations are 8,000-15,000 feet (2,440-4,570 meters). Highest known elevation is 16,470 feet (5,020 meters) near 8° 30' N, 71° 05' W. Ridges are steep, with deep valleys running southwest-northeast. The snow line is near 14,500 feet (4,420 meters).

The Coastal Mountains (Cordillera de la Costa) begin at Barquisimeto and continue eastward to the tip of the Paria Peninsula opposite Trinidad. East of Valencia (at 10° 20' N, 68° 00' W), the main range splits into two parallel ranges separated by about 25 miles (40 km). The northern range stops on the Caribbean coast at Cape Codera (Cabo Codera) and restarts on the western side of the Paria Peninsula near Barcelona. The southern range

runs continuously east to end at the coastal plains of the Gulf of Paria near 11° N. Elevations in both ranges average 3,000-6,000 feet (915-1,830 meters). But the northern range, which rises almost immediately on the Caribbean coast, has several peaks that reach nearly 8,000 feet (2,440 meters) in the section between Maracay and Caracas. The maximum height of 8,990 feet (2,740 meters) occurs just northeast of Caracas. Elevations increase again in the Serrania de Turimiquire east of Barcelona. This range, the continuation of the southern Coastal mountains, has a maximum elevation of 8,660 feet (2,640 meters) near 10° 05' N, 63° 55' W. Terrain gradients range from steep--especially in the higher elevations and along the immediate Caribbean coast--to rolling hills in the lower portions. There is a marked similarity to the coastal mountains of southern California.

VEGETATION. Throughout the Andes ranges, vegetation is a reflection of temperature (read "altitude") and precipitation (read "windward" and "leeward"). With this in mind, vegetation types are described as follows:

In Ecuador, cultivated land occurs along much of the coast from the Colombian border south to 2° S and again south of 2° 45' S. Western and southern slopes of the Clay Hills have thorn brush, scrub, and grassland. Areas immediately inland of the Gulf of Guayaquil along the Daule and Babahayo Rivers have mangrove swamps. The highest ridges of the Clay Hills are covered with deciduous forest reaching heights of 25 to 80 feet (7 to 24 meters). Both the western slope of the Cordillera Occidental and the eastern slope of the Cordillera Oriental see a continuation of lowland tropical rain forest as high as 6,000 to 8,000 feet (1,830 to 2,440 meters), depending on local wind flow and the resultant precipitation. A smaller version of the tropical rain forest, modified for colder temperatures and called "cloud forest," grows on these slopes between 6,000-8,000 and 10,000 feet (1,830-2,440 and 3,050 meters). But between 10,000 and 12,000 feet (3,050 and 3,660 meters), steadily decreasing temperature and precipitation turns the "cloud forest" into "evergreen scrub," a growth composed of dense interlocking evergreen shrubs and small trees that is fully as dense as the tropical rain forest and cloud forest. Above 12,000 feet (3,660 meters) lower temperatures and rapidly decreasing precipitation cause the evergreen scrub to give way to grassland that also extends down the inter-mountain slopes into inter-mountain valleys. The mostly coarse grass also contains clumps of stunted trees in sheltered areas. Flat areas may have some shallow marsh. As elevations approach the permanent snow line at 14,500 feet (4,440 meters), vegetation disappears. Because of the lack of precipitation, only desert-like thorn bush and scrub gr... above 10,000 feet (3,050 meters) in the extreme southern portions of the ranges (south of 3° 30' S). Intermountain valleys are cultivated wherever possible; main crops are corn and other grains.

In Colombia, vegetation altitude zones are similar to Ecuador's, but with the addition of coffee plantations in the inter-mountain valleys between 3,500 and 6,000 feet (1,065 and 1,830 meters). These plantations have closely-spaced coffee bushes, usually 3 to 5 feet (0.9 to 1.5 meters) high and shaded by widely-spaced, flat-topped trees. Tree heights range up to 40 feet (12 meters).

In Venezuela, the ranges southwest of Barquisimeto also have a smaller version of the tropical rain forest at elevations up to 10,000 feet (3,050 meters). Between 10,000 feet (3,050 meters) and the snowline at 14,500 feet (4,440 meters), the forest degenerates to scrub grassland. Little vegetation grows near the snow line. East of Barquisimeto, vegetation on the Caribbean-facing side of the northernmost east-west range rapidly turns into desert scrub that continues along the Caribbean side of the northern range eastward to the Paria Peninsula. Tropical rain forest of the type found in southwestern Venezuela occurs above 1,000 feet (305 meters) in the southern range east of Maracay to about 40 miles (65 km) east-southeast of Caracas, and again above 1,000 feet (305 meters) on the Paria Peninsula. Dense two-tiered deciduous forest, with an upper story of relatively open trees that reach 40 feet (12 meters), occurs in the rest of the mountains. These trees are leafless from early February through May. An understory of evergreen shrubs reaches heights of 3 to 10 feet (0.9 to 3 meters).

SEASONAL DIVISIONS. The region south of 2° N, depending upon altitude, has a southern hemisphere wet season, while the rest of the region has one more like the northern hemisphere. To further complicate the study of weather here, the Ecuador coast rapidly transitions from a wet climate to a very dry marine climate, similar to that of Baja California or northern Chile. The seasonal portion of this study is therefore subdivided into: *the Andes south of 2° N* and *the Andes north of 2° N.*

5.4.1 THE ANDES FROM 5° S TO 2° N

CLIMATIC ZONES. As may be inferred from the foregoing discussions, climate in the Andes is based largely on altitude. Certain climatic zones based on elevation and recognized by the Ecuadorians are shown in Figure 5-30 and described below. Note that the permanent snowline here is higher than in Peru and Northern Chile.

Hot and dry: Elevations below 1,300 feet (400 meters)--the coastal plain.

Hot and wet: Elevations from 1,300 feet (400 meters) to 3,300 feet (1,000 meters).

Temperate: From 3,300 to 6,550 feet (1,000 to 2,000 meters).

Cold: From 6,550 to 10,000 feet (2,000 to 3,050 meters).

High and cold: Above 10,000 feet (3,050 meters).

Snowfall: Above 15,700 feet (4,800 meters).

Permanent snow line: 17,000 feet (5,200 meters).

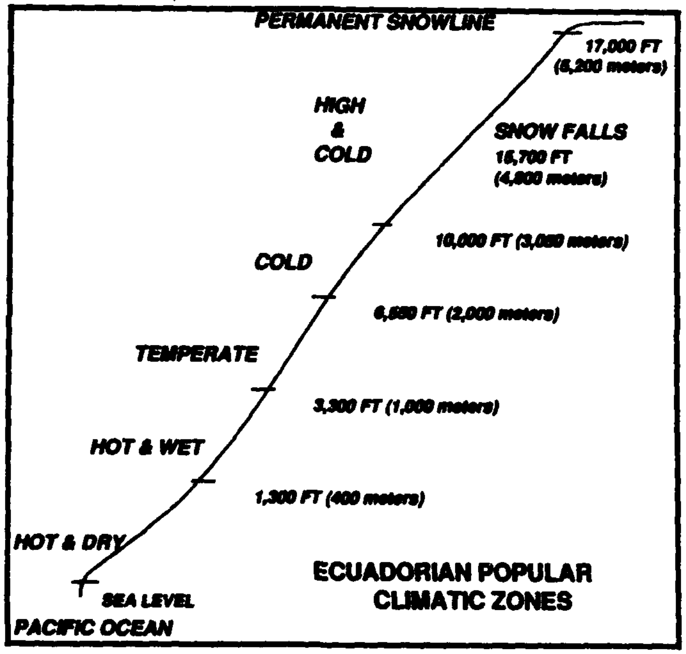


Figure 5-30. Climatic Zones Based on Elevation: Ecuador.

THE EFFECTS OF ENSO ON ANDES CLIMATE. A major phenomenon that has a major, if intermittent, effect on this region is the El Nino/Southern Oscillation, or ENSO. Although this phenomenon, which is much larger and slower than any synoptic disturbance, has a dramatic effect on the weather of all South America, that effect is most strongly felt in this region. ENSO usually occurs only once every 4 to 7 years and lasts from 18 to 24 months. A thorough discussion of the ENSO is beyond the scope of this study, and it is discussed here only from a Pacific South American coast viewpoint. The ENSO results in drastic sea surface temperature increases, often to 81°F (27°C), or to tropical levels. The prevailing southeasterly wind dies, to be replaced by equatorial westerlies or southwesterlies. Precipitation increases by one to two orders of magnitude; months that would normally have 0.1 inch (25 mm) of rain or drizzle now get 10 to 12 inches (250 to 300 mm). While the ENSO cycle seems to be near 27 months, there is no reliable pattern of intensities or onset/ending times. As of 1989, there was no known accurate means for forecasting a particular ENSO occurrence or its strength.

GENERAL WEATHER. The primary wet season ends in late April as the Bolivian Anticyclone moves northward to near 5° S before dissipating. The central and eastern Andes, however, see a secondary, lighter rainy season that runs from late September through November. This minor wet season is apparently related to an increase in heavy convection as the sun and the Amazon Basin portion of the Monsoon Trough move southward. As is usual in the tropics, purely "solar" rainfall seasons lag the solar cycle by about 2 months.

Along the Pacific coast and in the western Andes, there is only one wet season: November to April. But over the high central Andes and the eastern foothills, the primary wet season is from January to April (when 66% of the precipitation occurs); a secondary, but less intense, wet season runs from mid-September through mid-December, apparently related to the western Amazon Basin, where heavy precipitation occurs all year. Sufficient moisture is forced up the eastern Andes canyons from the Amazon Basin to form thunderstorms and heavy cumulus along the eastern Andes ridges. This convection then moves westward into the central highlands.

When the ENSO phenomenon occurs, it changes Andes weather drastically. The effects are most noticeable along the coast and on the western approaches to the Andes below 5,000 feet (1,500 meters). Specific effects depend on the ENSO's strength and range from only a slightly longer and wetter rainy season to one that lasts for up to 8 months and produces routine heavy cumulus, cumulonimbus, and torrential rains. For the actual effects of the 1982-1983 ENSO--the strongest since records have been kept here--see any of many articles on the subject in professional meteorological journals.

SKY COVER. Along the coast, night and early morning cloud cover is 5-9/10 stratus/stratocumulus with bases at 400-700 feet (120-215 meters) and tops from 1,500 to 2,000 feet (455 to 610 meters). Stratus dissipates rapidly by 0900 LST. By 1100 LST a sea breeze is established; heavy cumulus forms at 2,500 feet (765 meters) over ridges where forced lift is strong enough to break through the subsidence inversion. Tops reach 15,000 to 20,000 feet (4.6 to 6.1 km). Isolated showers occur in the afternoons. Guayaquil, because of the bay at whose head it is located, is different; the proximity of the bay and forced lift over the hills on either side of the city results in considerably more rainfall at Guyaquil than at other coastal locations. Heavy convective showers are a daily event here during the rainy season. South of 4° S, however, showers become fewer, but stratus is much more persistent, dissipating along the immediate coast only by late afternoon.

Over the western Andes foothills above 2,500 feet (760 meters) and in the central Andes and intermountain valleys, a complex series of diurnal, location-dependent showers develops. Higher ridges see heavy cumulus and isolated cumulonimbus during the late morning and afternoon. Precipitation occurs primarily between 1300 and 2000 LST. Nights see mountain winds draining into valleys. In deeply eroded canyons, these winds warm sufficiently to make lower portions semi-arid. Over wide, high river valleys, converging mountain winds generate evening and night cumulus with bases from 1,000 to 2,000 feet (300 to 600 meters) AGL and tops from 12,000 to 18,000 feet (3.7 to 5.5 km). Most precipitation in these valleys falls between 2000 and 0700 LST.

Over the eastern Andes ranges, upslope flow results in persistent multilayered clouds to 5,000 feet (1,525 meters) MSL with bases near 2,000 feet MSL (610 meters). Most parts of the east side of the eastern Andes, therefore, are totally obscured except in some very deep river canyons. Thunderstorms form in early afternoon over ridge tops, reaching 40,000 to 50,000 feet (12.2 to 15.2 km).

Sky cover over mountain ridges and in mountain valleys is extremely variable. Satellite imagery indicates standing heavy convective clouds during the dual rainy seasons over the high and eastern Andes. These clouds reach their greatest coverage during late morning and afternoon. Pilot reports and fragmentary weather records indicate that hail is common with heavy showers above 10,000 feet (3,000 meters). Mesoscale convective clusters have been observed moving westward from the Amazon Basin over the high Andes during January and February.

Summarized climatic data for this part of the Andes is extremely difficult to obtain, but Figures 5-31 through 5-34 provide a representative sampling of the extreme northern Peruvian coast and coastal/valley Andes station data for Ecuador. Figure 5-31 gives mean monthly frequencies of ceiling/visibility less than 3,000/7 for Tumbes, Peru. Figure 5-32 gives mean monthly frequency of visibility less than 7 miles (11 km) for Guyaquil, Ecuador, and Talara, Peru. Lesser frequencies at Guyaquil are due to its sheltered location at the head of a deep bay.

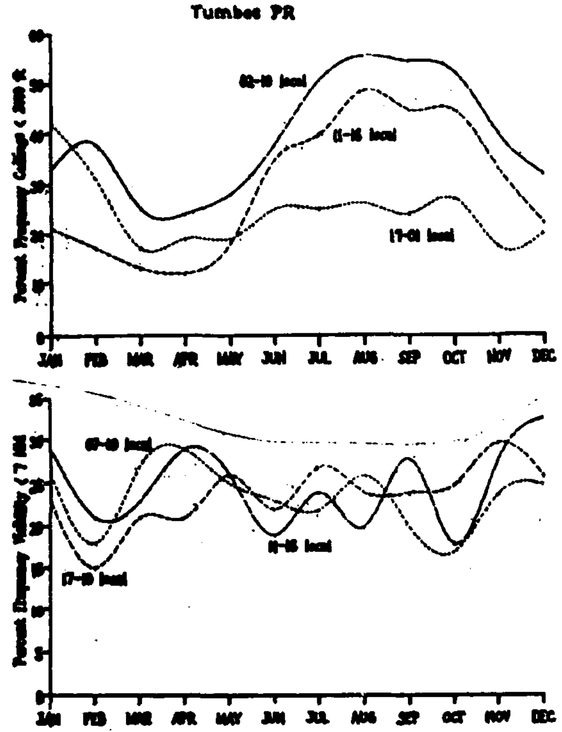


Figure 5-31. Percent Frequency Ceiling/ Visibility <3,000/7: Tumbes, Peru.

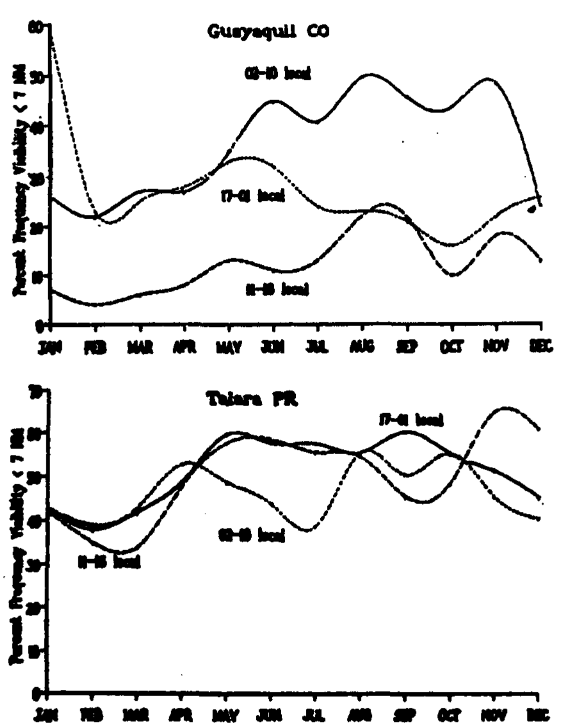
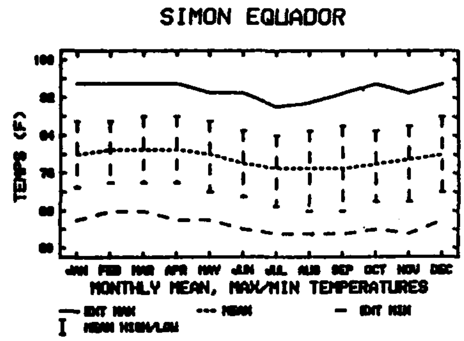


Figure 5-32. Percent Frequency Visibility <7 Miles: Guyaquil, Ecuador, and Talara, Peru.

Figure 5-33 gives precipitation and temperature data for Guyaquil (Simon), and Figure 5-34 provides thunderstorm days, precipitation, and temperature for Quito, Ecuador. Note the differences between Guayaquil (on the coast) and Quito (in a high Andes valley).



SIMON EQUADOR
GUAYAQUIL

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	MAX MON PRECIP
JAN	95	80	66	6.5	87	73	20.4
FEB	96	81	68	7.4	87	74	14.4
MAR	95	81	68	8.1	88	74	17.1
APR	95	81	66	6.2	88	74	16.2
MAY	93	80	66	1.6	87	72	8.1
JUN	90	78	64	.6	86	71	5
JUL	90	77	63	0	84	69	.1
AUG	91	77	63	0	86	68	0
SEP	93	77	63	0	86	69	.1
OCT	95	78	64	.2	86	70	.7
NOV	93	78	63	0	86	70	.2
DEC	95	80	66	.6	88	72	2.4

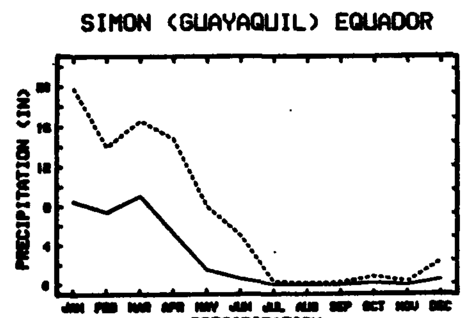
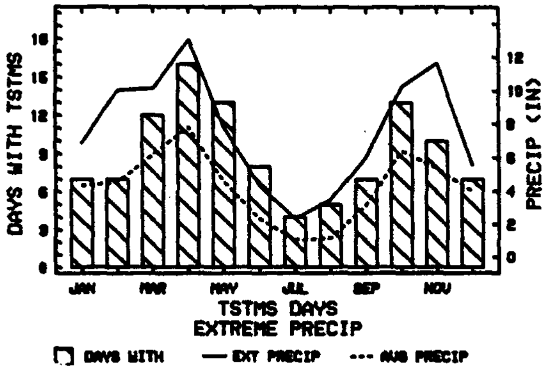


Figure 5-33. Precipitation and Temperature: Guayaquil (Simon), Equador.

QUITO ECUADOR (Observatory)



QUITO ECUADOR
(Observatory)

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	EXTRM PRECIP
JAN	79	55	36	3.7	72	46	7	5.9
FEB	77	55	37	3.9	70	46	7	6.6
MAR	77	54	39	5.3	70	48	12	9.7
APR	77	55	39	6.7	70	49	16	11.2
MAY	79	56	39	3.9	72	46	13	6.7
JUN	79	55	39	2	70	46	9	3.7
JUL	78	55	36	.9	72	45	4	2
AUG	79	56	37	1	73	45	5	3
SEP	82	56	36	2.7	73	45	7	5.2
OCT	81	55	37	5.5	72	46	13	9.9
NOV	79	55	37	4.6	70	46	10	10
DEC	80	55	37	3.4	70	46	7	4.9

Figure 5-34. Thunderstorm Days, Precipitation, and Temperature: Quito, Ecuador.

WINDS. Local surface winds reflect terrain and local effect wind patterns rather than macroscale gradients. Even along the immediate coast, land and sea breezes dominate the local wind fields.

THUNDERSTORMS are confined to the central and eastern Andes. During both rainy seasons, weather stations in high Andes valleys report thunderstorms every other day. Quito averages almost 110 thunderstorm days a year. Pilot reports and discussions with experienced airline meteorologists indicate that thunderstorms occur almost daily during both wet seasons over the eastern Andes, and that they are still common--occurring on 1 day out of 4--during the dry seasons.

PRECIPITATION. Maximum precipitation occurs between 3,300 and 4,500 feet (1,000 and 1,400 meters) in the western Andes, and between 2,600 and 4,000 feet (800 and 1,200 meters) in the eastern Andes. Wet season precipitation in the high central Andes valleys ranges from 29.5 to 35.4 inches (750 to 900 mm). Fully 90% of western Andes (and 66% of central and eastern Andes) precipitation falls during the primary (January-April) wet season. Figures 5-35 and 5-36 give mean monthly precipitation for January through April (primary wet season) and September through November (secondary wet season), respectively.

TEMPERATURE. Temperatures depend more on altitude than on any other factor. Mean annual temperatures are 81°F (27°C) at sea level; 70°F (21°C) at 3,300 feet (1,000 meters); 68°F (20°C) at 5,000 feet (1,500 meters); and 55°F (13°C) at 10,000 feet (3,000 meters). Diurnal range is from 12 to 20°F (6 to 11°C). Seasonal variations range from 4 to 8°F (2 to 4°C).

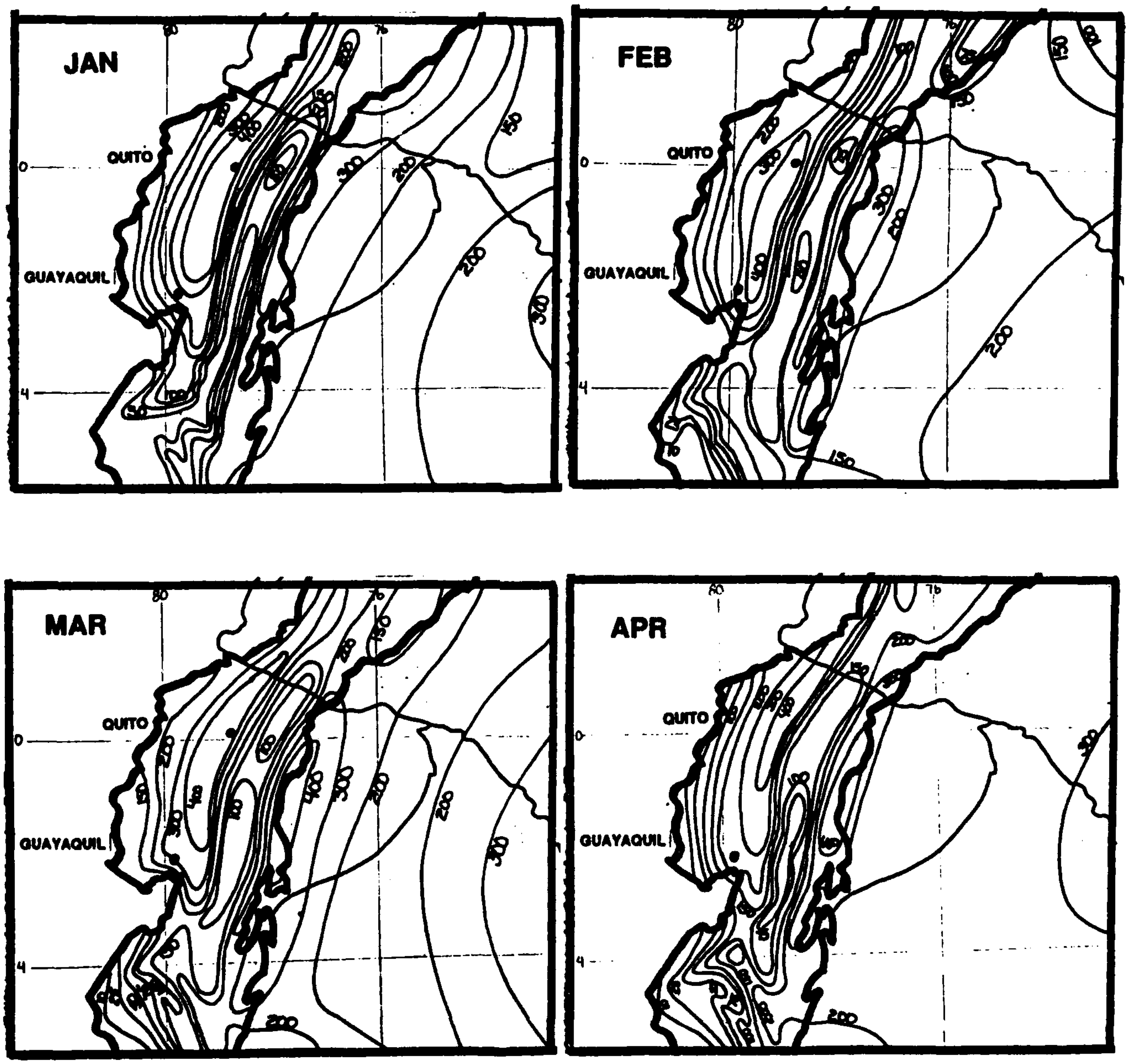


Figure 5-35. Mean Monthly Precipitation: January-April.

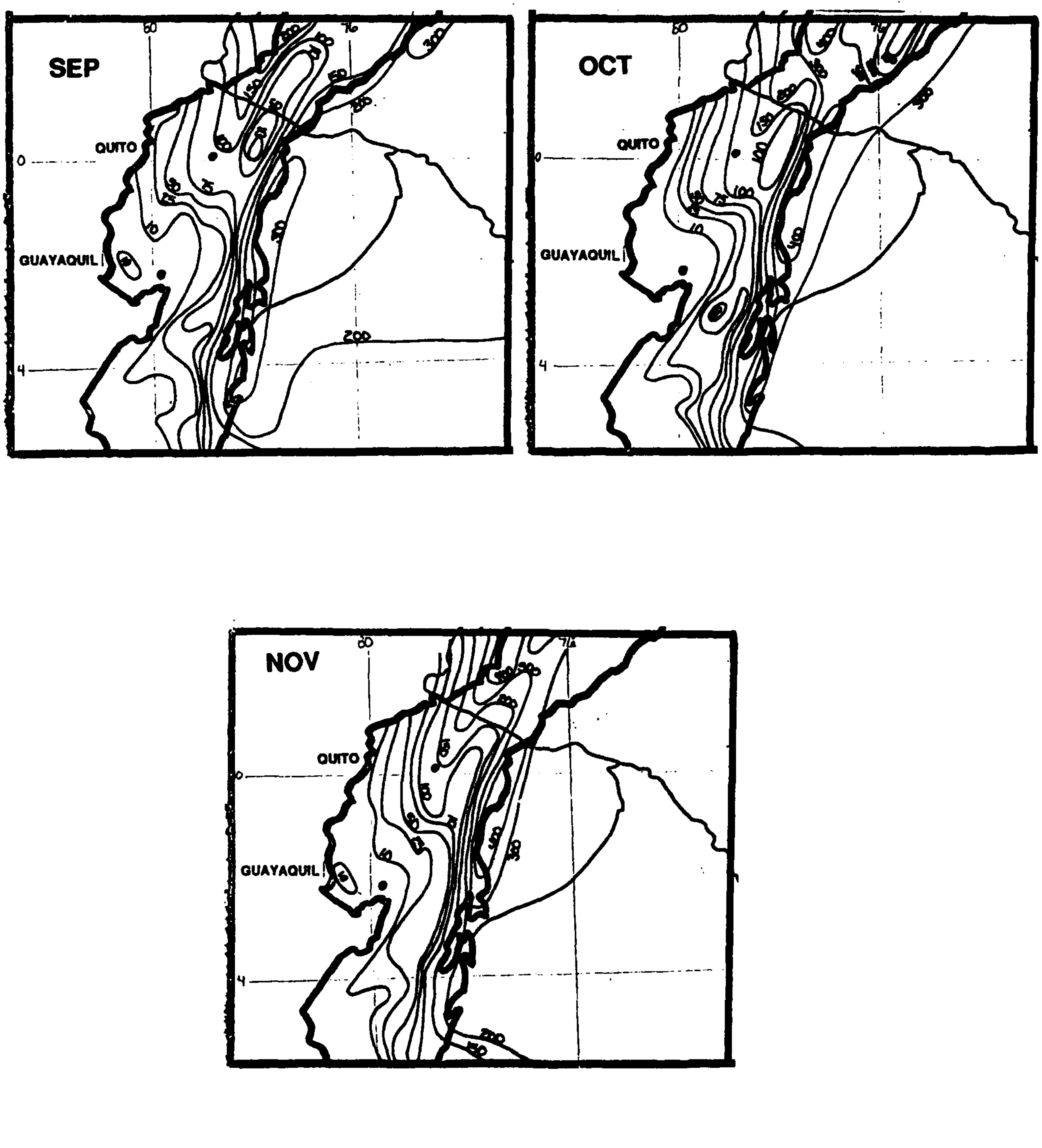


Figure 5-36. Mean Monthly Precipitation: September-November.

GENERAL WEATHER. ENSO events can also occur during the dry season, with the same effect as during the wet season, which see. Note the height of the upper-level inversion at Guyaquil during the dry season, shown in Figure 5-37.

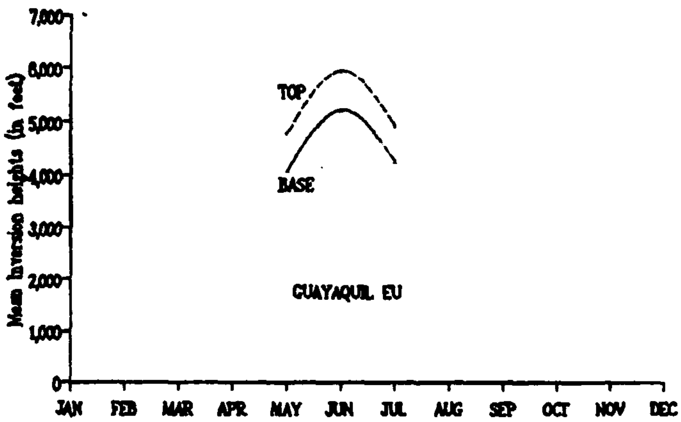


Figure 5-37. Mean Inversion Heights: Guayaquil, Equador.

SKY COVER. Along the coast, night and early morning sees 5-9/10 stratus/stratocumulus, with bases 400-700 feet (120 to 215 meters) and tops 1,500-2,000 feet (455 to 610 meters). North of 3° S, stratus dissipates rapidly by 0900 LST. But south of 3° S, the stratus persists day and night as a heavy, dull blanket. By 1100 LST, the sea breeze has been established. Advancing onshore 5-15 miles with this breeze during afternoon and early evening, the stratus moves back to the immediate coast in late morning. Precipitation is confined to drizzle from the stratus/stratocumulus decks. Inland, very isolated heavy cumulus may form at 2,500 feet (765 meters) over ridges where forced lift is strong enough to break through the subsidence inversion. Tops reach 15,000 to 20,000 feet (4.6 to 6.1 km). Isolated showers occur in the afternoons north of 4° S. Except for the above, sky cover is much the same as during the wet season, which see.

WINDS. Same as wet season.

THUNDERSTORMS. Same a. wet season.

PRECIPITATION. Maximum dry season precipitation occurs at elevations between 3,300 and 4,500 feet (1,000 and 1,400 meters) in the western Andes, and between 2,600 and 4,000 feet (800 asnd 1,200 meters) in the eastern Andes. Precipitation in the high central Andes valleys ranges from 29.5 to 35.4 inches (750 to 900 mm). See Figures 5-38 (May, June, July, August) and 5-39 (December) for mean monthly dry season precipitation.

TEMPERATURE. Temperatures are about the same as during the wet season, with one exception: Along the coast south of 3° S underneath the stratus, maximum temperatures average 68°F (20°C); minimums 60°F (16°C).

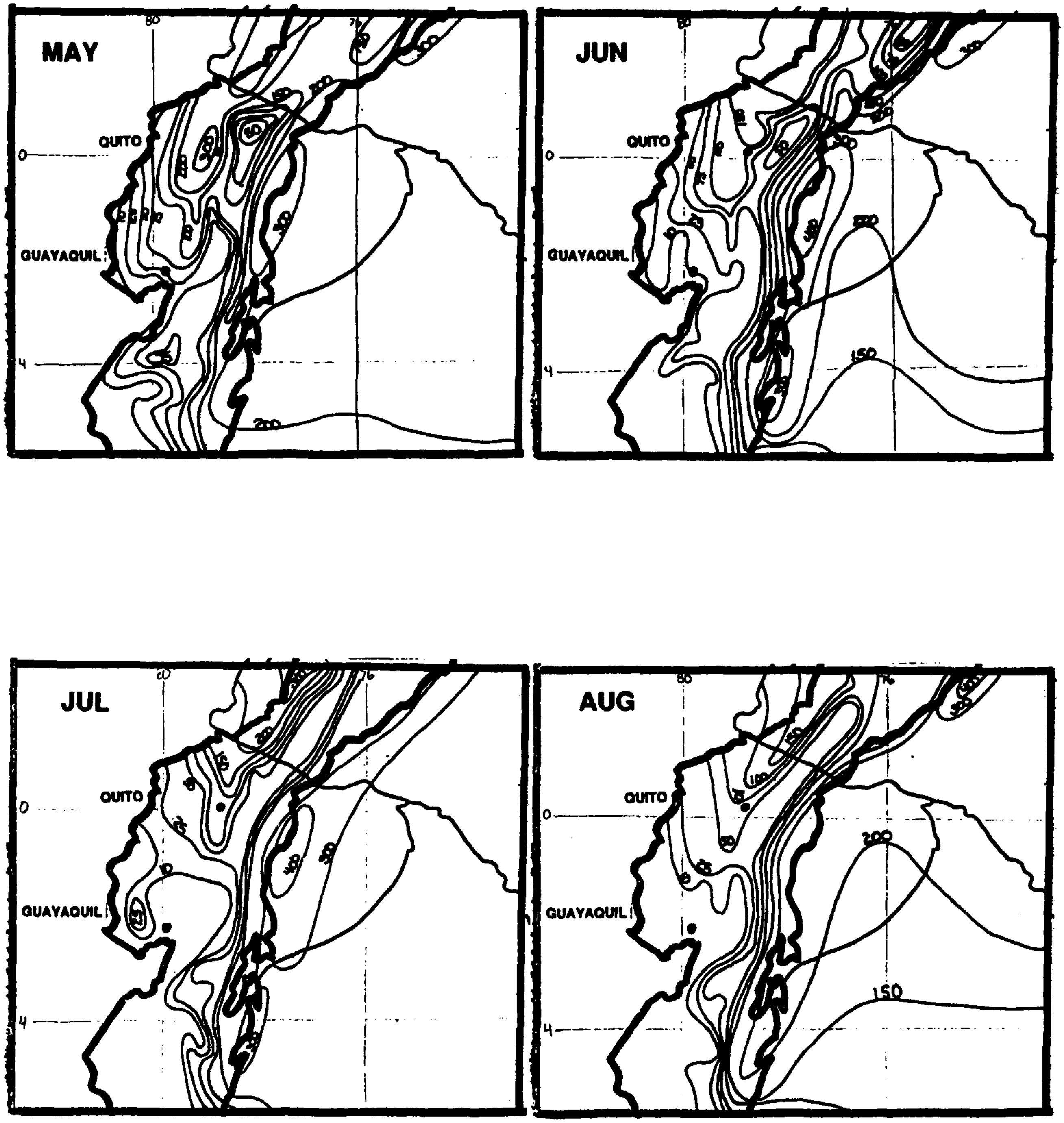


Figure 5-38. Mean Monthly Precipitation: May-August.

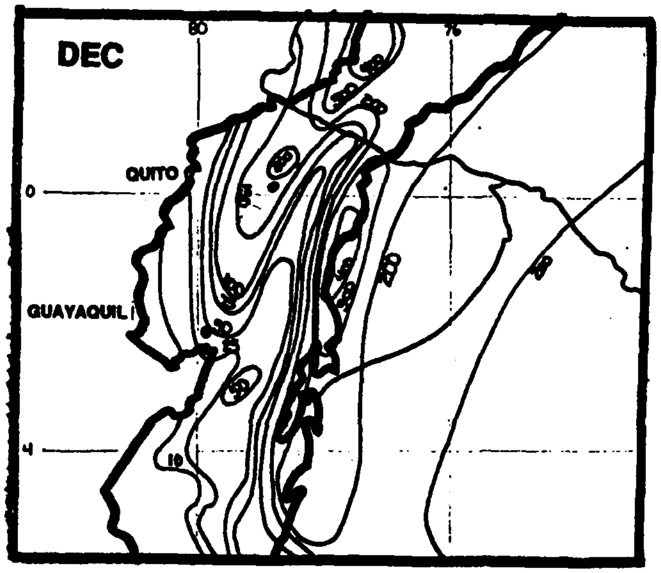


Figure 5-39. Mean Precipitation: December.

5.4.2 THE ANDES NORTH OF 2° N

CLIMATIC ZONES. Colombians recognize the same climatic zones as proposed by the Ecuadorians and as shown in Figure 5-40. The permanent snow line here is at 17,000 feet or (5,200 meters) the same as south of 2° N, but higher than in Peru and northern Chile.

SEASONAL REGIMES. Between the Equator and 2° N, the Andes climate changes to the northern hemisphere's "double wet and dry season" regime. Below 4,600 feet (1,400 meters), the western Andes range and its coastal foothills do not see "dry seasons," per se, but precipitation decreases slightly in late May and early June, and again in September.

RAINFALL MAXIMA. At elevations between 3,300 and 4,600 feet (1,000 and 1,400 meters) near 5° N, annual rainfall in this region is almost 400 inches, or about 10 meters!

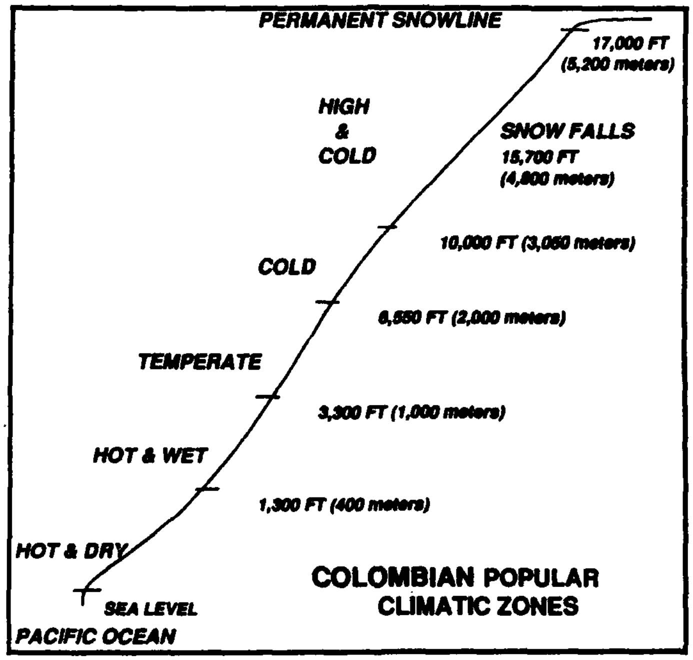


Figure 5-40. Climatic Zones Based on Elevation: Colombia.

GENERAL WEATHER. In the central and eastern Andes, the primary wet season begins in mid-October and ends in late December. In the eastern Andes foothills, there is a secondary (minor) wet season that begins in early March and ends in late May. In the western Andes foothills, there is no dry season, per se--only a slight decrease in precipitation from late May to early June, and again in September.

Figure 5-41 gives mean heights for the trade wind inversion when it is present over Maracay, Venezuela. Note that the inversion is present here during the secondary March-May wet season, but at greater heights than during the primary dry season.

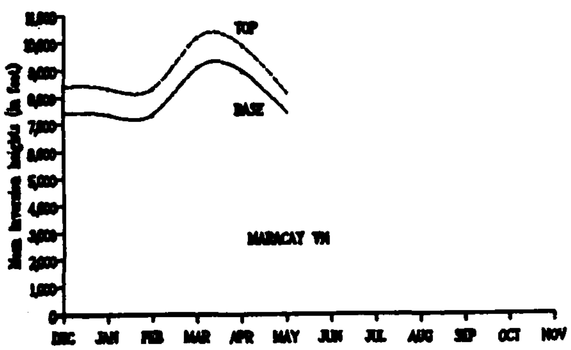


Figure 5-41. Mean Trade Wind Inversion Height: Maracay, Venezuela.

Upper-level winds show the effect of the Andes as a heat source at the boundary layer. Wind variability is best reflected in the 00Z data--especially at 10,000 feet (3,050 meters); Figure 5-42 shows mean upper-level wind directions from 10,000 to 30,000 feet over San Antonio-Tuchira, a station in the extreme southwestern part of the Venezuelan Andes. Figures 5-43, 5-44, and 5-45 give upper-level wind directions for Bogota, Colombia, and Maracay, Venezuela. Both wet seasons here have westerly upper tropospheric (30,000 feet/9 km) winds overlying low-level easterlies, or winds with an easterly component.

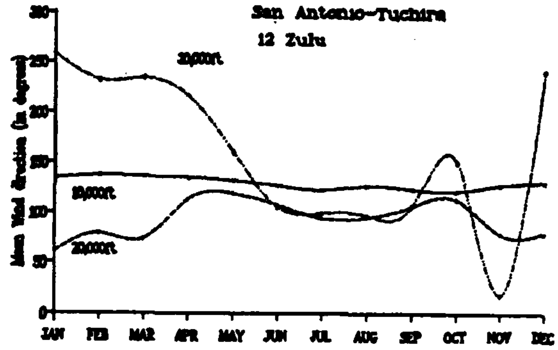


Figure 5-42. 1200Z Upper-Level Winds: San Antonio-Tuchira, Venezuela.

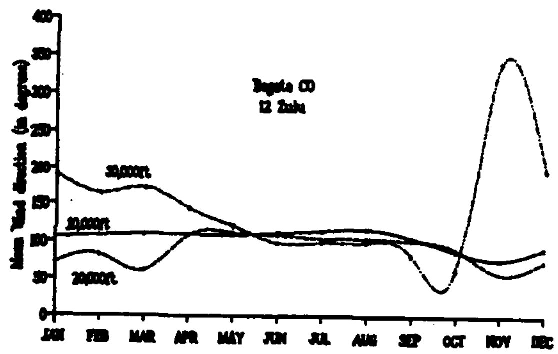


Figure 5-43. 1200Z Upper-Level Winds: Bogota, Colombia.

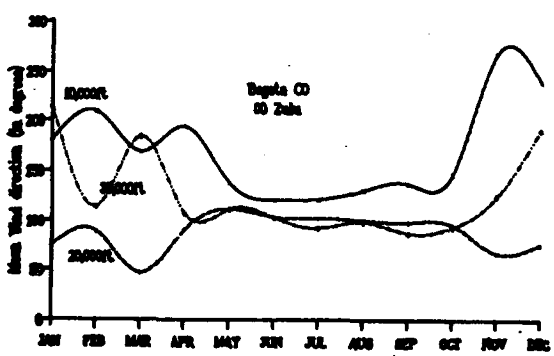


Figure 5-44. 0000Z Upper-Level Winds: Bogota, Colombia.

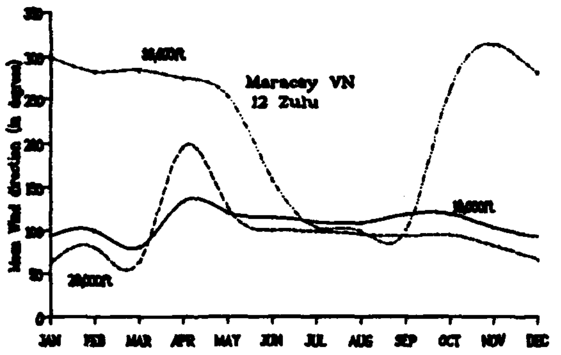


Figure 5-45. 1200Z Upper-Level Winds: Maracay, Venezuela.

Polar incursions from either hemisphere affect the northern and eastern Andes. During northern hemisphere summers, very strong southern hemisphere polar outbreaks cross the Guyana Highlands into the Orinoco Basin and drive the Monsoon Trough into, or even over, the Venezuelan Andes. Extremely strong incursions have been known to drive all the way to the southern Caribbean. When they do, the southern sides and crests of the Andes get strong convection and heavy rains.

During the northern hemisphere winter, very strong North American polar surges rarely, but occasionally, reach the Venezuelan coast, normally in February or March. The result is very heavy convection along the immediate Caribbean coast, with almost continuous heavy rains. Duration is usually 24 to 36 hours.

Upper-level "cool pools" can come from either hemisphere. The favored months are in the originating hemisphere's winter, but these phenomena have been observed at other times. Satellite imagery shows them as widespread areas of disorganized convection that still move as units.

The Santa Marta Massif, a huge volcanic cluster in extreme northeastern Colombia, has a climatic regime similar to that of Mauna Kea or Mauna Loa in Hawaii. Reaching to nearly 20,000 feet (6.1 km), the mountain becomes a focus for heavy convection during the wet season due to the loss of the tradewind inversion and the close proximity of the Monsoon Trough.

SKY COVER. Over the western Andean foothills below 5,000 feet (1,400 meters), a steady progression of heavy cumulus and cumulonimbus moves onshore in the afternoon and evening. Heavy rainshower maximums vary by elevation. Between 650 and 2,600 feet (200 and 800 meters), the maximum is in early evening; between 2,600 and 5,000 feet (800 and 1,500 meters), heavy rain showers occur between 1400 and 1900 LST. Above 5,000 feet (1,400 meters) and in the central Andes and intermountain valleys, the higher ridges see heavy cumulus and isolated cumulonimbus to 45,000 feet (13.7 km) in late morning and afternoon; precipitation occurs primarily between 1300 and 2000 LST. Nocturnal mountain winds drain into valleys; in deeply eroded canyons, these winds warm sufficiently to make lower portions semiarid. Over wide, high river valleys, converging mountain winds generate evening and night cumulus with bases at 1,000 to 2,000 feet (300 to 600 meters) AGL and tops at 12,000 to 18,000 feet (3.7 to 5.5 km). Most precipitation in these valleys falls between 2000 and 0700 LST. Figure 5-46 shows Bogota mean monthly frequencies of visibilities less than 7 miles (11 km). Figure 5-47 gives frequency of occurrence of mean monthly ceilings below 3,000 feet (900 meters) and visibilities less than 7 miles (11 km) for Cali, Colombia. Figure 5-48 gives thunderstorm days, precipitation, mean maximum, mean minimum, extreme temperatures, and maximum 24-hour precipitation for Bogota, Colombia.

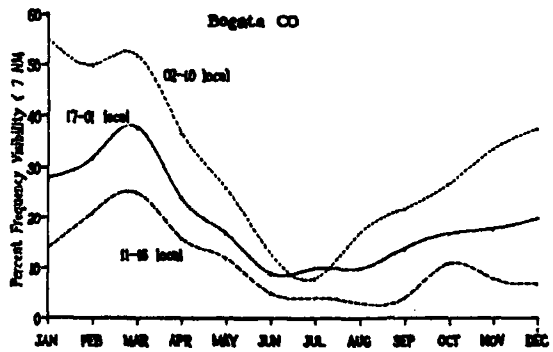


Figure 5-46. Percent Frequency of Visibility <7 Miles: Bogota, Colombia.

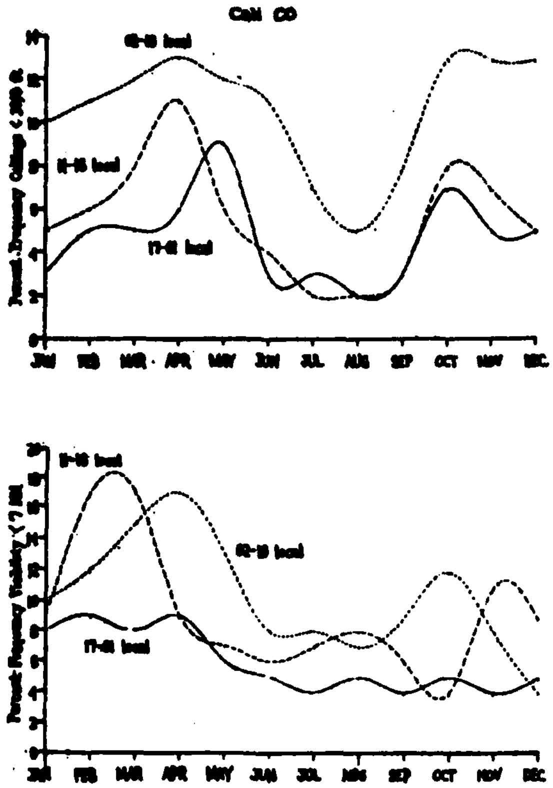
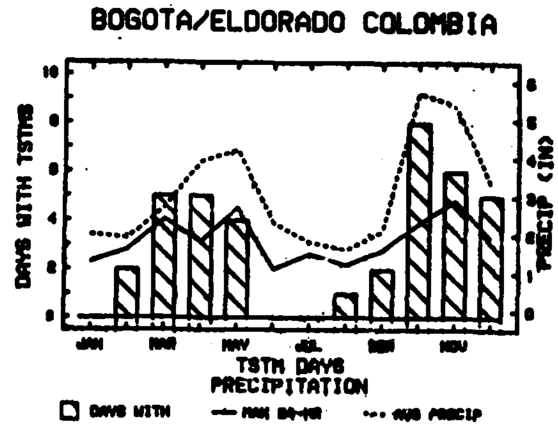


Figure 5-47. Percent Frequency of Ceiling/ Visibility <3,000/7: Cali, Colombia.



BOGOTA/ELDORADO COLOMBIA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	77	55	[illegible]	2	67	[illegible]	[illegible]	1.[illegible]
FEB	77	[illegible]	[illegible]	1.[illegible]	67	44	2	1.6
MAR	77	57	[illegible]	2.7	67	47	5	2.4
APR	76	57	34	[illegible]	[illegible]	[illegible]	5	1.[illegible]
MAY	76	57	[illegible]	4.2	[illegible]	[illegible]	4	2.[illegible]
JUN	74	[illegible]	[illegible]	[illegible]	[illegible]	47	[illegible]	1.1
JUL	74	[illegible]	33	1.[illegible]	64	47	[illegible]	1.[illegible]
AUG	74	[illegible]	[illegible]	1.6	[illegible]	46	1	.[illegible]
SEP	75	[illegible]	[illegible]	2.1	[illegible]	46	2	.6
OCT	76	[illegible]	[illegible]	5.7	[illegible]	47	[illegible]	2.[illegible]
NOV	76	[illegible]	33	5.4	[illegible]	47	6	2.[illegible]
DEC	77	[illegible]	34	3.3	[illegible]	44	5	1.[illegible]

Figure 5-48. Thunderstorm Days, Precipitation, and Temperature: Bogota, Colombia.

Over the eastern Andean ranges, upslope flow results in persistent multilayered clouds up to 5,000 feet (1,525 meters) MSL. Bases are near 2,000 feet MSL (610 meters). Obviously, most of the east side of the eastern Andes is totally obscured except for some very deep river canyons. Thunderstorm tops reach 40,000 to 50,000 feet (12.2 to 15.2 km) in early afternoon over ridge crests. Figure 5-49 gives frequency of ceiling and visibility less than 3,000/7 for San Antonio-Tuchira, located in the extreme southwestern Venezuelan Andes near the Colombian border.

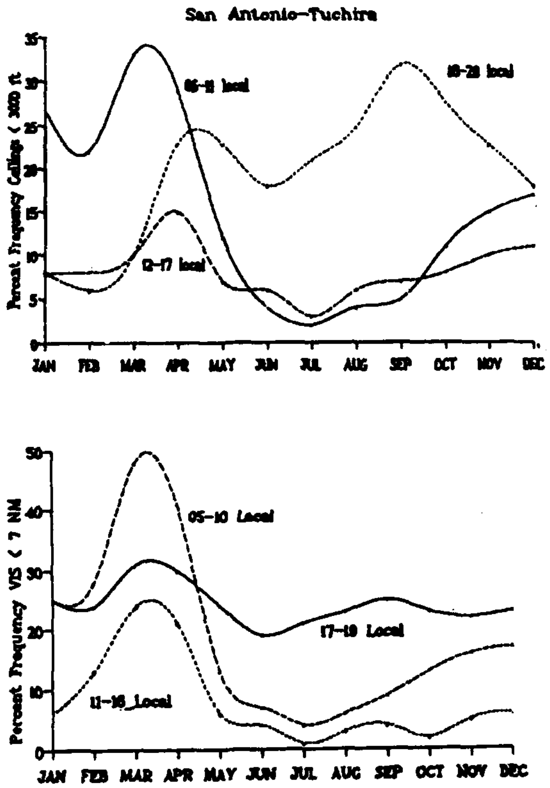
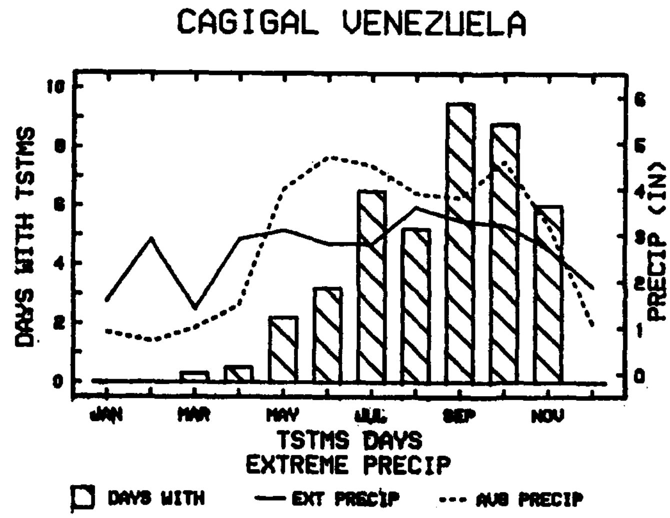


Figure 5-49. Percent Frequency of Ceiling/Visibility <3,000/7: San Antonio-Tuchira.

Over the Santa Marta Massif, cloud cover forms near the 3,300 foot (1,000 meters) contour. Early morning sees virtually clear skies, but 5-7/10 stratocumulus/cumulus) forms by 0900 LST with tops near 6,000 feet (1,830 meters). By 1200 LST, towering cumulus and islolated cumulonimbus have formed over higher peaks on the northeastern and central areas. Tops range from 15,000 to 40,000 feet (4.6 to 12.2 km). Scattered to numerous rain showers occur from 1400 to 1900 LST. Skies clear by 2200 LST.

Along the Venezuelan Caribbean coast, night and early morning see 1-3/10 stratus/stratocumulus with bases at 400-700 feet (120-215 meters) and tops at 1,500 to 2,000 feet (455 to 610 meters). Stratus dissipates rapidly by 0800 LST. By 1100 LST, very isolated heavy cumulus forms at 2,500 feet (765 meters) over ridges where forced lift is strong enough to break through the subsidence inversion. Tops reach 15,000 to 20,000 feet (4.6 to 6.1 km). Isolated showers occur in the afternoon. Figure 5-50 gives summarized data for Cagigal (Caracas), Venezuela; Figure 5-51 gives ceiling and visibility frequencies for Simon Bolivar International Airport, 15 miles north on the Caribbean coast. Figures 5-52 and 5-53 give the same information for Barcelona, Venezuela.



CAGIGAL VENEZUELA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	87	67	51	.9	78	59	0	1.6
FEB	86	67	52	.7	80	58	0	2.9
MAR	92	69	53	1	82	60	.3	1.4
APR	91	70	54	1.8	83	62	.6	2.9
MAY	91	71	58	4	83	64	2.2	3.1
JUN	89	71	58	4.7	83	64	3.2	2.8
JUL	86	70	58	4.5	81	64	6.5	2.9
AUG	89	71	58	3.9	82	64	5.2	3.6
SEP	88	71	60	3.8	83	64	9.5	3.3
OCT	90	70	57	4.8	82	64	8.9	3.2
NOV	86	69	57	3.2	80	63	6	2.7
DEC	85	68	52	1.1	78	62	0	1.9

Figure 5-50. Thunderstorm Days, Precipitation, Temperature: Cagigal (Caracas), Venezuela.

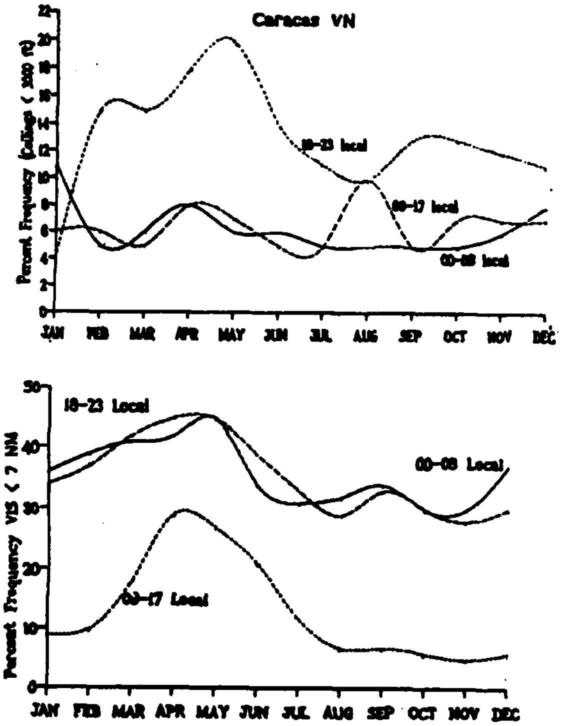


Figure 5-51. Percent Frequency Ceiling/ Visibility <3,000/7: Simon Bolivar International Airport, Caracas.

BARCELONA VENEZUELA

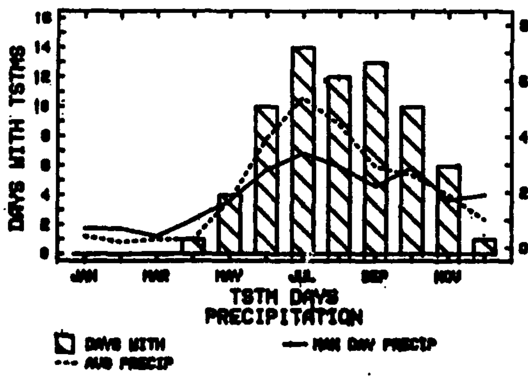


Figure 5-52a. Thunderstorm Days and Precipitation: Barcelona, Venezuela.

BARCELONA VENEZUELA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	24 HR PRECIP
JAN	95	78	60	.4	90	[illegible]	0	.7
FEB	95	78	61	.2	[illegible]	68	0	.7
MAR	96	81	62	.3	91	71	0	.4
APR	97	82	67	.3	91	72	1	.1
MAY	98	82	68	1.7	[illegible]	73	4	1.7
JUN	98	82	68	3.8	90	74	10	2.8
JUL	96	81	68	5.4	90	73	14	3.4
AUG	98	82	69	4.4	90	73	12	2.9
SEP	97	82	67	2.9	90	73	13	2.2
OCT	96	81	68	2.8	90	71	10	2.9
NOV	95	81	67	1.9	90	71	6	1.7
DEC	95	80	68	1	90	70	1	1.8

Figure 5-52b. Thunderstorm Days, Precipitation, and Temperature: Barcelona, Venezuela.

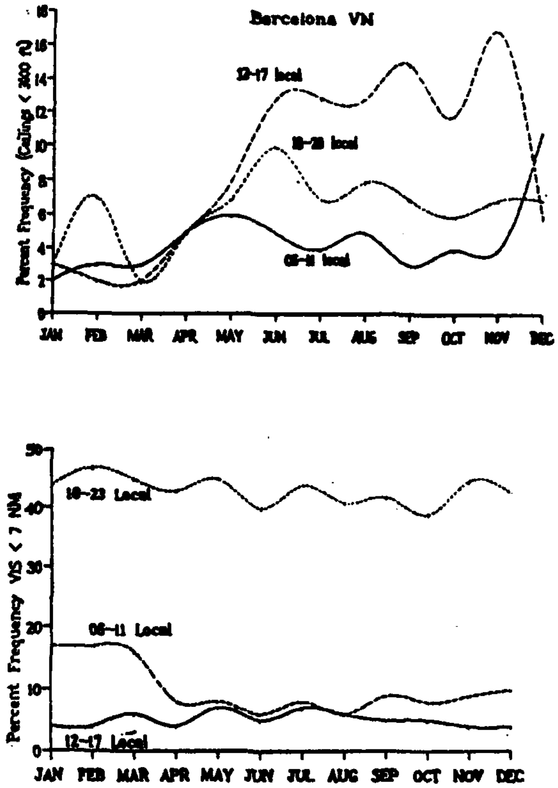


Figure 5-53. Percent Frequency Ceiling/ Visibility <3,000/7: Barcelona, Venezuela.

With cold surges from either hemisphere, lines of heavy cumtlus and cumulonimbus form along windward slopes in the Venezuelan Andes near 2,500 feet (760 meters) and over ridges; tops are from 20,000 to 40,000 feet (6.1 to 12.2 km). Similar conditions occur with the passage of "cool pools."

WINDS. Mean surface winds on the Andean massif are variable. In free air above ridge crests, winds south of 9° N during northern hemisphere summer tend to be easterly at 25 to 30 knots; winds north of 9° N are light easterly to variable. During northern hemisphere winter, winds north of 8° N are westerly at 15 to 25 knots; south of 8° N, they are variable. (Refer to Figures 5-42 through 5-45 for representative upper-level wind directions over the Andes north of 8° N.)

Along the Venezuelan Caribbean coast, the low-level jet shown in Figure 5-54 flows over the immediate coast nearly year-round. It extends from just west of Trinidad to the eastern shore of the Gulf of Venezuela. Like most such phenomena, this jet varies diurnally, with a maximum at dawn and a minimum in mid-afternoon.

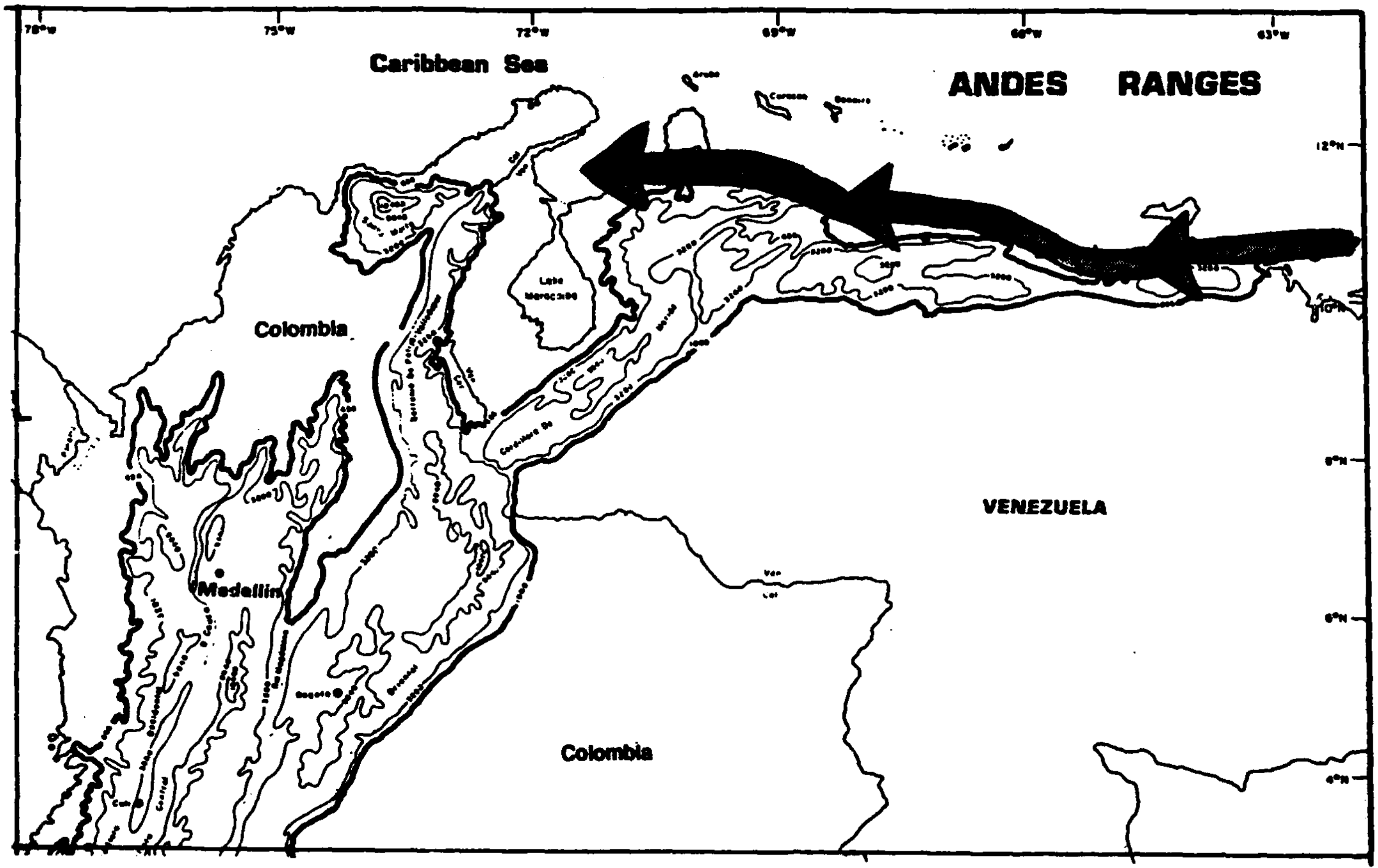


Figure 5-54. Venezuelan Coastal Low-Level Jet Stream.

THUNDERSTORMS are predominantly a characteristic of the summer hemisphere, but are common over the high and eastern/southern Andean slopes. Hail is common above elevations of 10,000 feet (3,000 meters).

PRECIPITATION. The Andes Massif is a heat source and a heat island. As a result, precipitation is lighter than might be expected. Equatorial westerlies, however, result in extremely heavy rainfall whose diurnal distribution falls into the two zones shown in Figure 5-55.

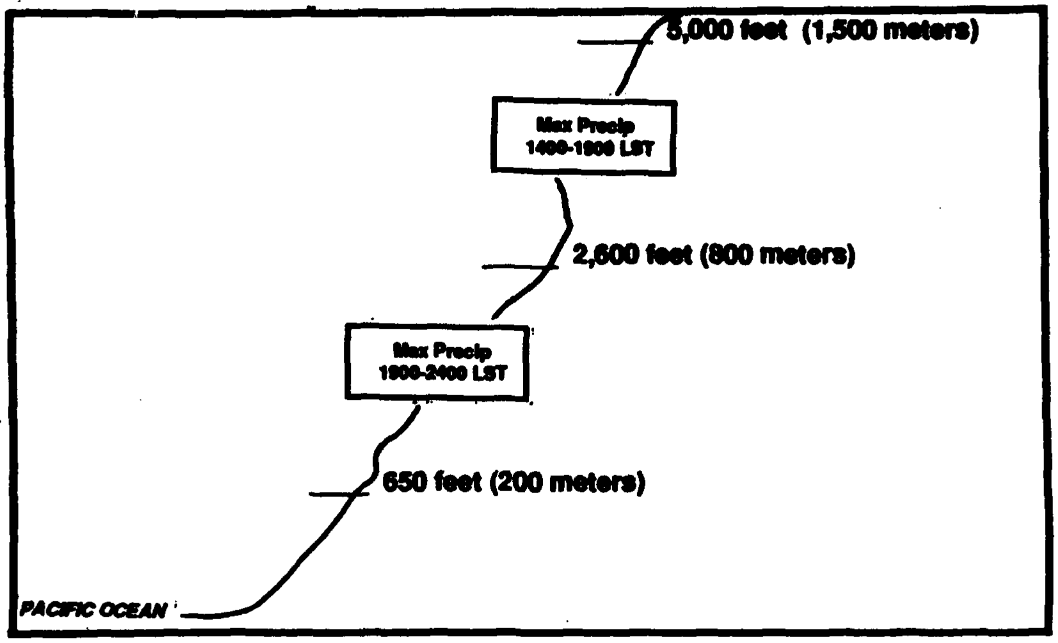


Figure 5-55. Times (LST) of Maximum Precipitation in Certain Altitude Zones.

Regions at elevations from 650 to 2,600 feet (200 to 800 meters) see rainfall maximums from 1900 to 2400 LST, while those regions between 2,600 and 5,000 feet (800 and 1,500 meters) have their maximums between 1400 and 1900 LST. Maximum rainfall occurs at elevations between 3,300 and 5,000 feet (1,000 to 1,400 meters), decreasing higher. Surges in the recurved equatorial westerlies are known to occur with periodicities near 5 days; the primary effect on the Colombian coast is to enhance rainfall. Figures 5-56 and 5-57 show mean monthly area precipitation for March through May and October through December, respectively.

TEMPERATURE. Temperatures here are affected more by altitude than any other factor. Mean annual temperatures are 81°F (27°C) at sea level; 70°F (21°C) at 3,300 feet (1,000 meters); 68°F (20°C) at 5,000 feet (1,500 meters); and 55°F (13°C) at 10,000 feet (3,000 meters). Diurnal range is 12 to 20°F (6 to 11°C). Seasonal variations range from 4 to 8°F (2 to 4°C). Low-level temperatures along the Venezuelan Caribbean coast are considerably warmer. Temperatures have reached 100°F (38°C) at Simon Bolivar International Airport at Caracas.

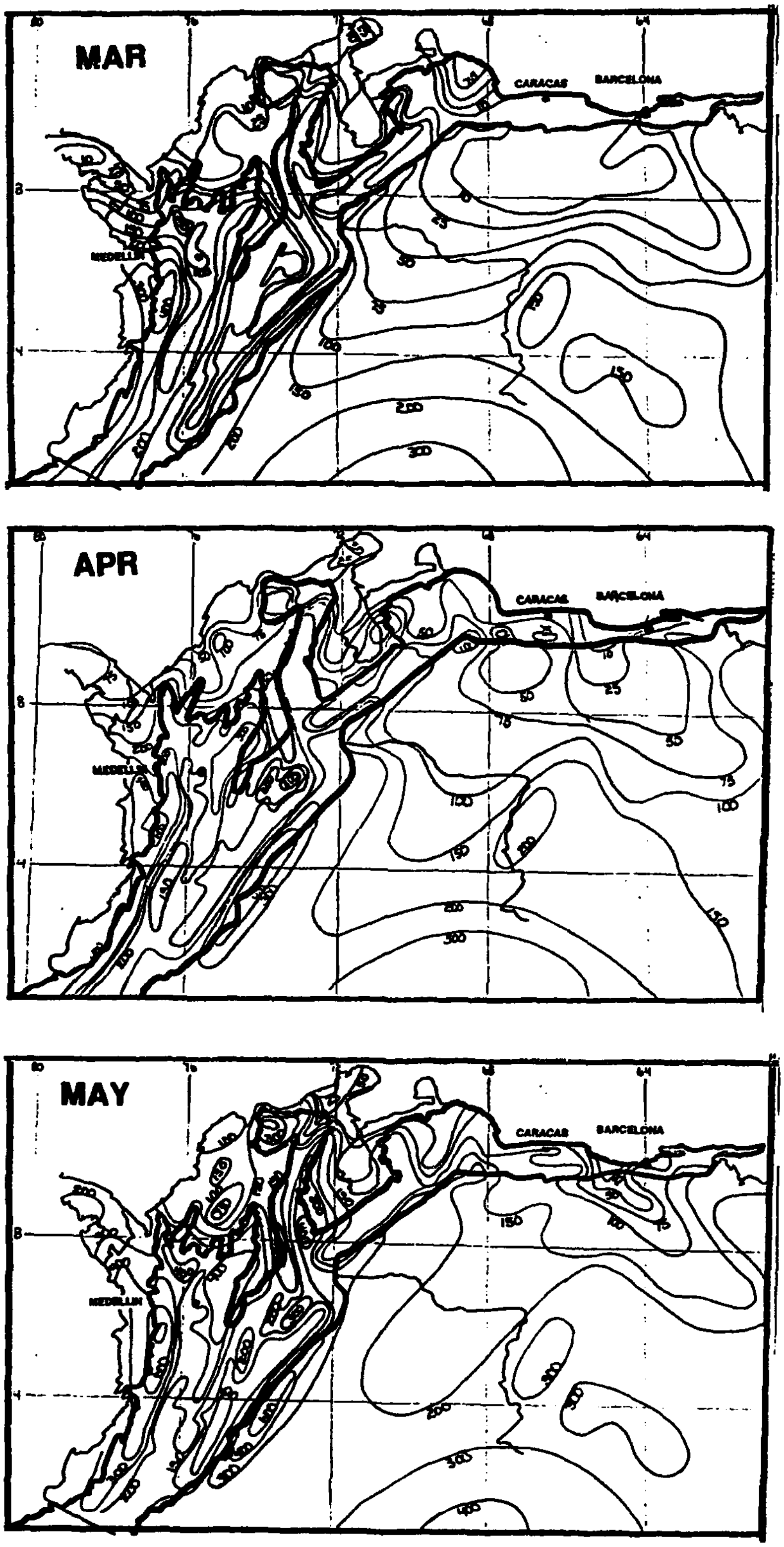


Figure 5-56. Mean Monthly Precipitation: March-May.

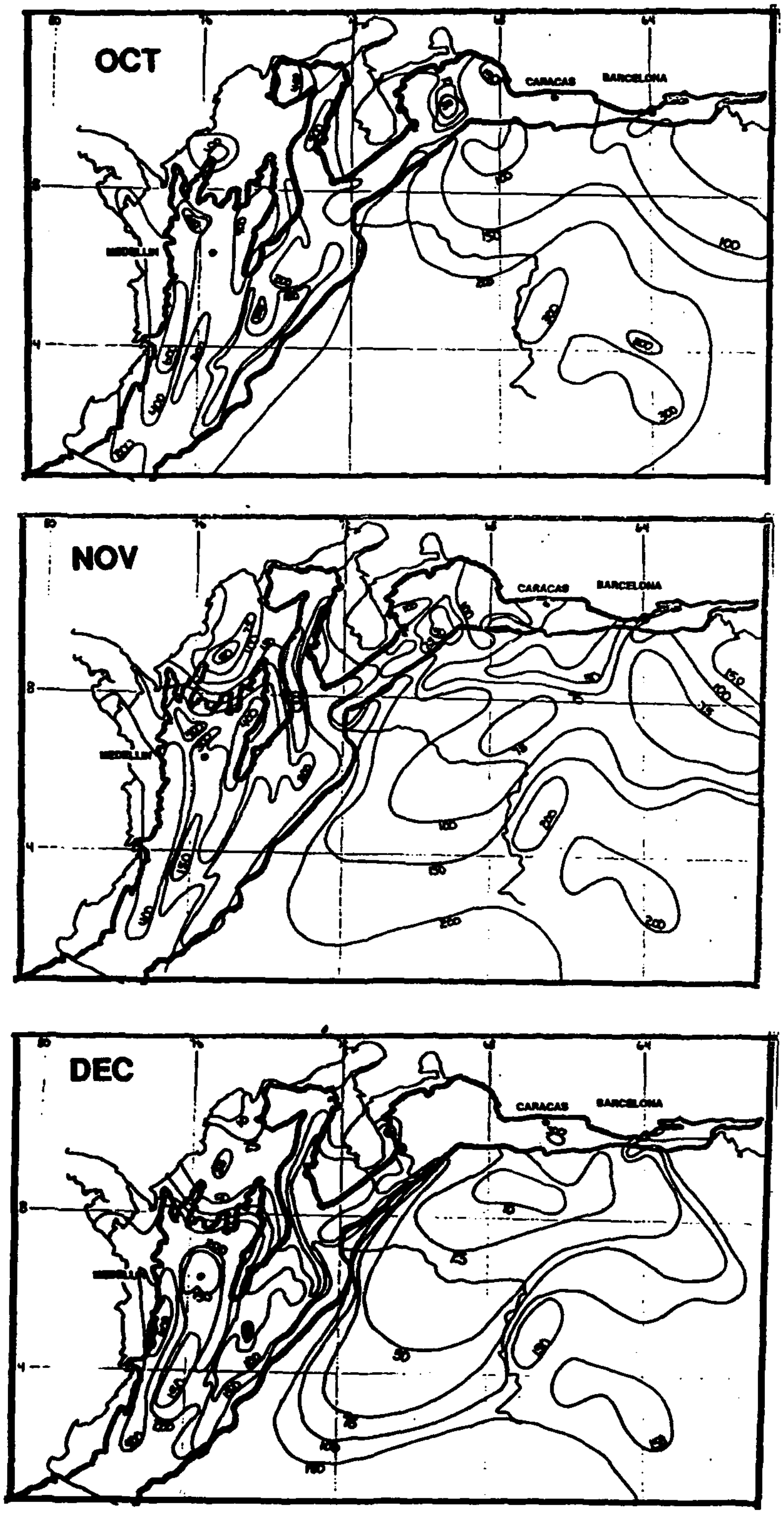


Figure 5-57. Mean Monthly Precipitation: October-December.

GENERAL WEATHER. June through August is the primary dry season here; January through February, the secondary. Note that the Pacific Colombian Andean foothills and western slopes (up to 8° N) have no definite dry season.

The northeasterly trades are at their strongest, both in speed and inversion strengths, during the secondary dry season. Flow is stable and dry. The weakness of the summer northeasterly trades and their convergence into the Monsoon Trough is compensated over extreme northern Venezuela and the Colombian Caribbean coast by upper-level subsidence. Figure 5-58 shows mean trade wind inversion heights when the inversion is present over Maracay, Venezuela. Note that the inversion is present in the northeasterly trades during the secondary dry season.

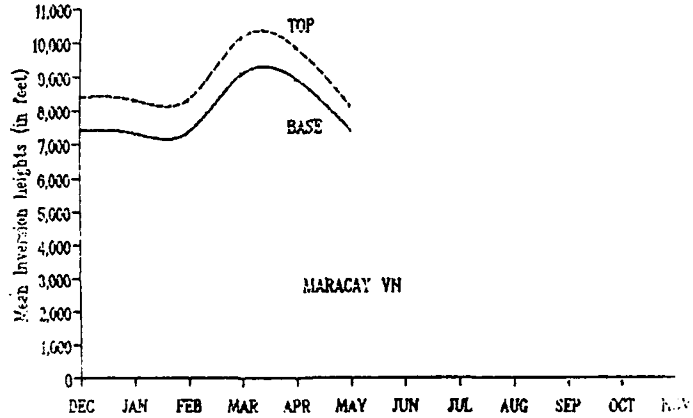


Figure 5-58. Mean Trade Wind Inversion Height: Maracay, Venezuela.

During northern hemisphere winter, a very strong North American polar surge rarely, but occasionally, reaches the Venezuelan coast, normally in February or March. The result is very heavy convection along the immediate Caribbean coast. Upper-level "cool pools" may move into the region from either hemisphere.

The Santa Marta Massif penetrates the northeasterly winter trade wind inversions. As a result, moist low-level air is forced up and around the mountain to near 10,000 feet (3,000 meters). The resulting leeside convergence zone produces cloud cover and rainfall, even during the dry seasons.

SKY COVER. Over the western Andean foothills, the eastern Andes, and the Santa Marta Massif, dry season sky cover is similar to that of the west season, which see.

Along the Venezuelan Andes inland from the Caribbean coast, only patchy heavy cumulus forms when the flow has been forced upward enough to break through the trade wind inversion.

On the Venezuelan Caribbean coast, nights and early mornings see 1-3/10 stratus/stratocumulus, with bases at 400-700 feet (120-215 meters) and tops at 1,500 to 2,000 feet (455 to 610 meters). Stratus dissipates rapidly by 0800 LST.

With cold surges from either hemisphere, the Venezuelan Andes see lines of heavy cumulus and cumulonimbus forming along windward slopes near 2,500 feet (760 meters) and over ridges; tops are from 20,000 to 40,000 feet (6.1 to 12.2 km). Similar conditions occur with the passage of a "cool pool."

WINDS. Mean dry season winds are similar to those of the wet season, which see. Along the Venezuelan Caribbean coast, a low-level jet (see Figure 5-54) flows over the immediate coast nearly all year. Like most such phenomena, it varies diurnally, with a maximum at dawn and a minimum in mid-afternoon.

THUNDERSTORMS are found only over the eastern Andean slopes facing the Amazon and Orinoco Valleys and over the Santa Marta Massif. Hail is common at elevations above 10,000 feet (3,000 meters).

PRECIPITATION. The Andes Massif is a heat source and a heat island; as a result, precipitation is lighter than might be expected. Maximum rainfall occurs at elevations between 3,300 and 5,000 feet (1,000 to 1,400 meters), decreasing above. Figures 5-59 and 5-60 show mean monthly precipitation for January-February and June-September, respectively.

TEMPERATURE. Dry season temperatures are much the same as those of the wet seasons, which see.

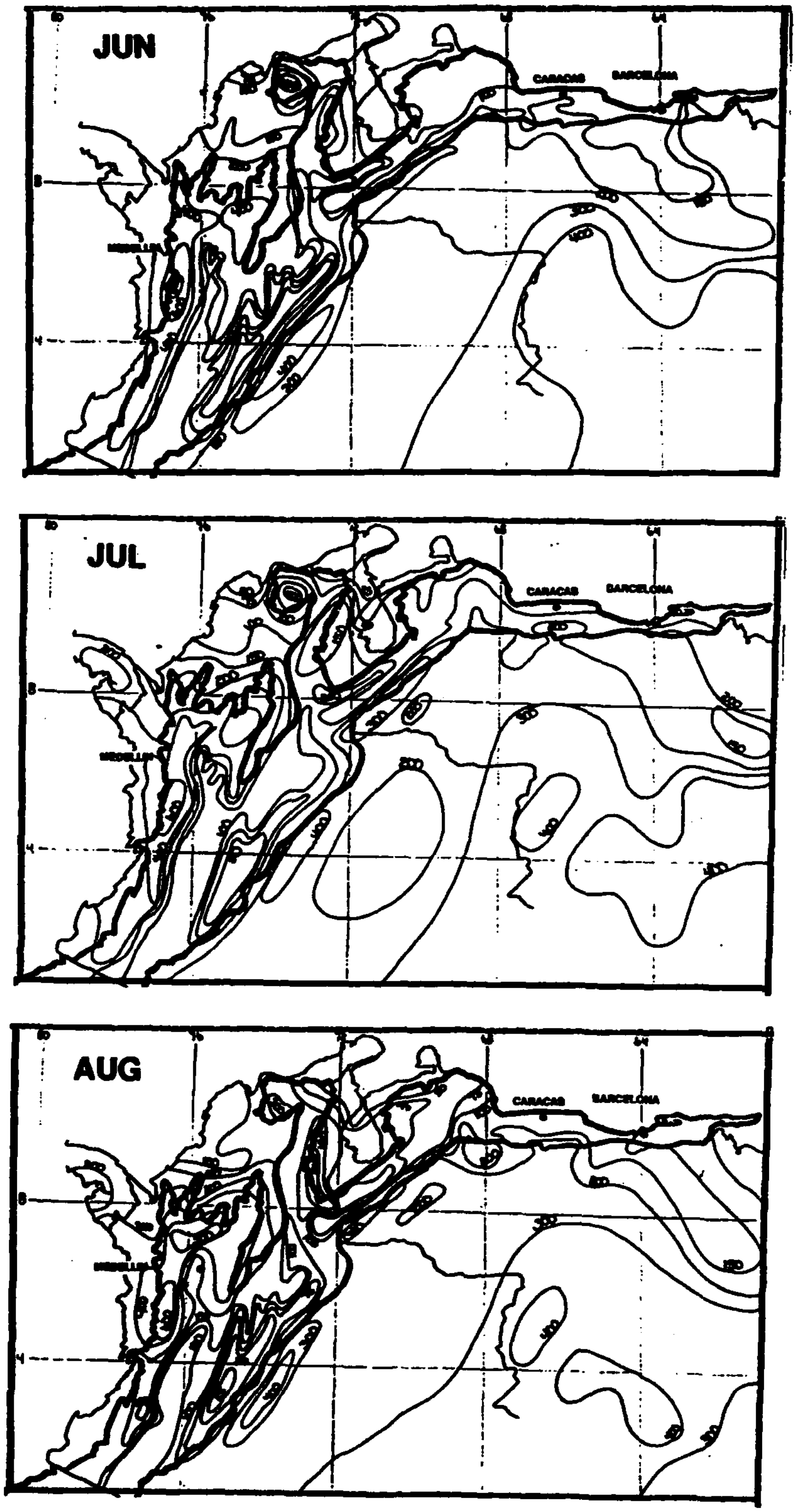


Figure 5-59. Mean Monthly Precipitation: June-August.

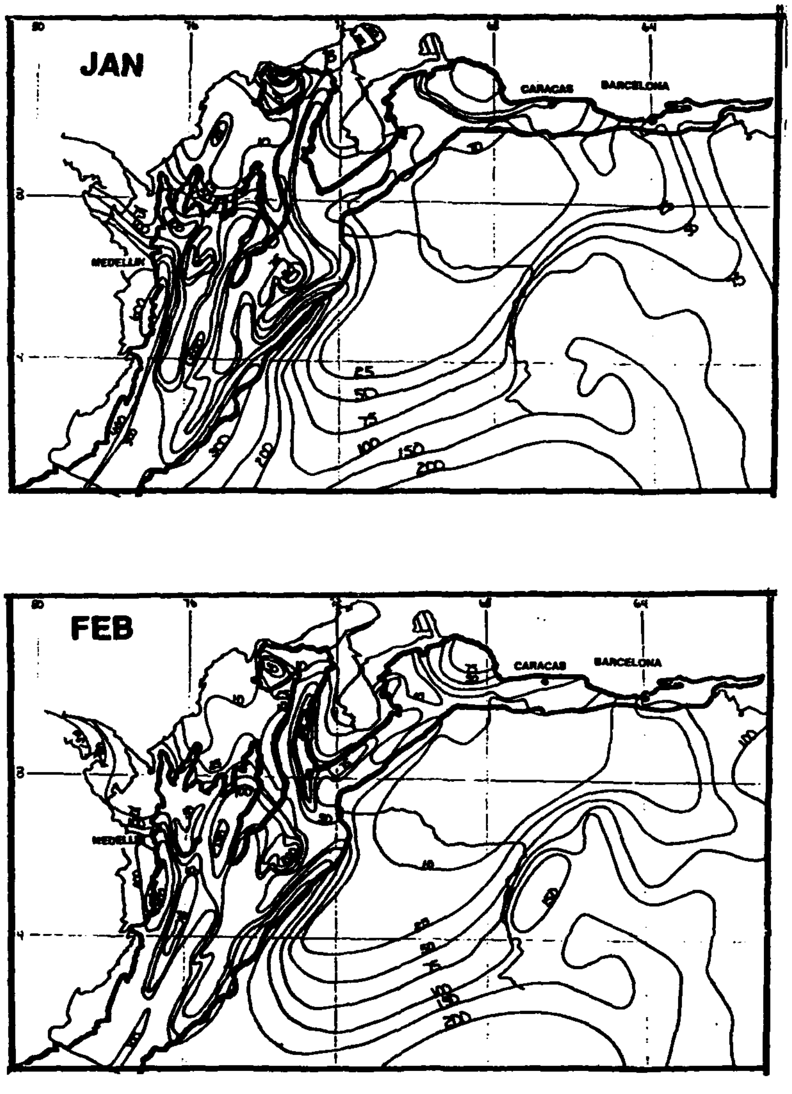


Figure 5-60. Mean Monthly Precipitation: January & February.

5.5 THE COLOMBIAN HIGHLANDS

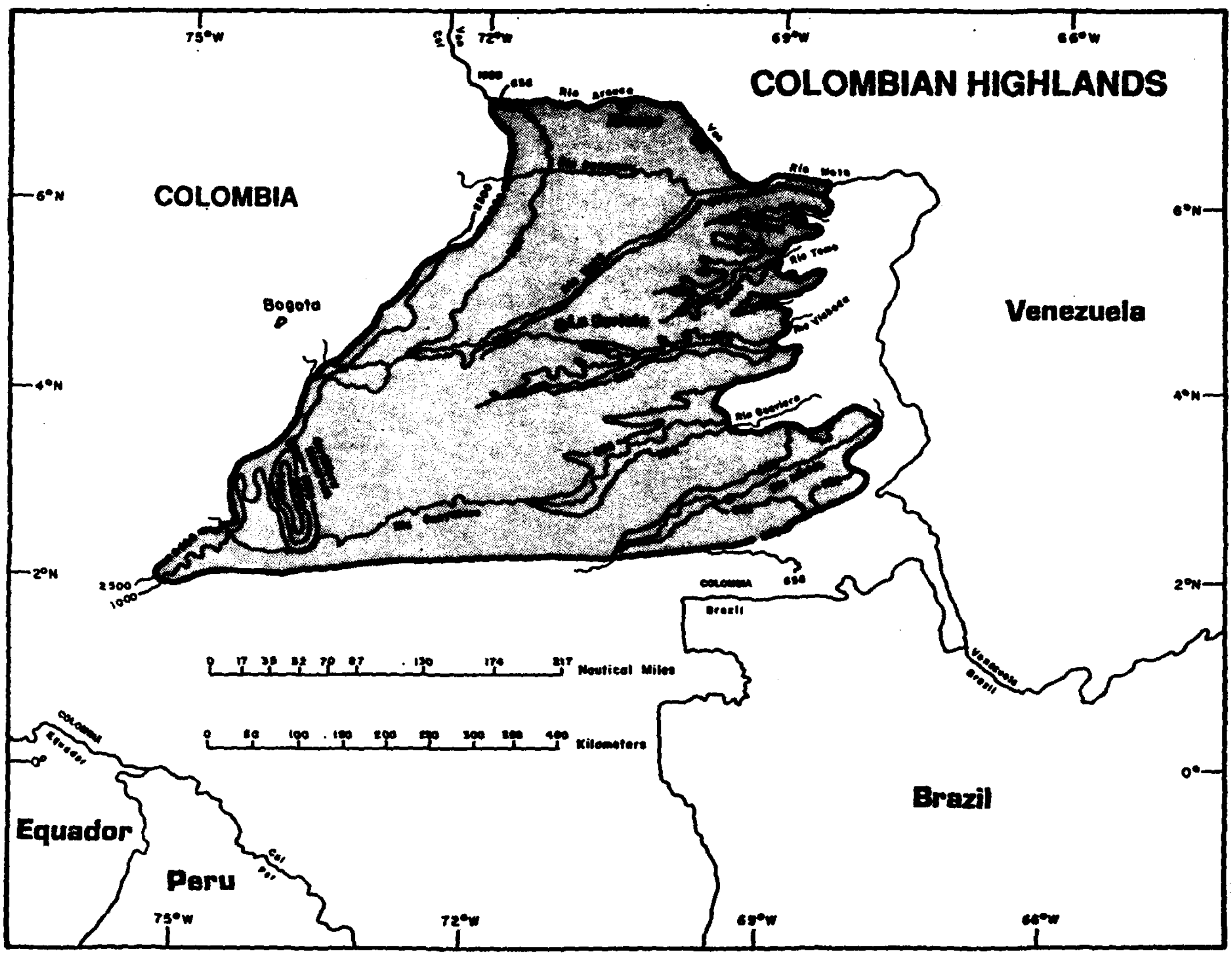


Figure 5-61. The Colombian Highlands. The Colombian Highlands lie in a great concave arc that starts just east of the Colombian Andes and extends northeastward to the border between southwestern Venezuela and northeastern Colombia. Elevations here range from 300 feet to 2,500 feet (100 to 750 meters). Most of the area is tropical savanna. Tropical forests are found only along immediate river shoreline areas.

COLOMBIAN HIGHLANDS GEOGRAPHY

BOUNDARIES. The region described here as the Colombian Highlands is bounded:

On the south by the 2,500-foot (760-meter) contour line at 3° N on the Colombia-Venezuela border, then west-southwestward to 2° N, 75° 10'W.

On the west by the eastern Andes slopes below 2,500 feet (760 meters) at the Guayabero River (at about 2° N, 75° 10'W) to 1,000 feet (328 meters) at the Aracura River on the Venezuela border.

On the north by the Venezuela border from its intersection with the 1,000-foot (328-meter) contour to its intersection with the 656-foot (200-meter) contour just west of the junction of the Meta and Orinoco Rivers.

On the east by a line southward along the 656-foot (200-meter) contour on the west side of the Orinoco River to 4° N, then south along the Venezuela-Brazil border from 4° N to 3° N.

TERRAIN. Most of the highlands is rolling plain cut by rivers flowing to the east and northeast. The extreme western portion includes the eastern slopes of the Andes, which are relatively steep as they rise abruptly from the plains.. In the extreme west, river gradients are also steep, with fast-running currents. But after leaving the Andes foothills, rivers become broader and shallower. Almost all rivers drain into the Orinoco River System. The Orinoco proper forms the eastern boundary of the area; rivers flowing through the northern part of the region reach the Orinoco through western Venezuela.

VEGETATION. Because of the rainshadow effects of the Guyana Highlands and the east-west mountain orientation in northern Venezuela (described in the "Andes Ranges" section), vegetation here is characteristic of the tropical savanna. Grasslands predominate, with occasional trees. Even the Andes foothills in this region do not have forests below 2,500 feet (760 meters). However, vegetation along rivers is like that of a tropical rain forest--as dense, but shorter.

GENERAL WEATHER. A rapid early April transition from the dry to the wet season progresses from southwest to north. As in the adjoining Orinoco Plains, the wet season is "winter," the dry season "summer."

SKY COVER. North of the Monsoon Trough in the retreating northeasterly trade winds, patchy low stratus occurs near dawn along rivers, dissipating by 0900 LST. Isolated cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset.

Patchy early morning stratus decks form in river valleys at elevations up to 2,000 feet (610 meters) in and south of the Monsoon Trough. Fog may or may not occur under the stratus, depending on precipitation. Otherwise, only scattered altocumulus/altostratus or cirrostratus occurs. By 1000 (LST), the stratus has dissipated. Heavy cumulus begins to form near 3,500 feet (1,070 meters). By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region. Tops vary from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered thunderstorms occur, dissipating after sunset. Patchy river stratus forms after midnight.

Figure 5-70 gives representative frequencies of ceilings below 3,000 feet (900 meters) and visibilities below 7 miles (11 km) at Gaviotas, Colombia, for daylight hours only; nighttime data is not available.

Worse conditions can be expected with mesoscale convective complexes in the Monsoon Trough; 4-7/10 stratus, with bases at 300 to 500 feet (90 to 150 meters) and tops at 1,500 to 2,500 feet (450 to 760 meters) form underneath stratocumulus/cumulus (bases 2,000-2,500 feet/610-760 meters). Isolated cumulonimbus is embedded in the cumulus/stratocumulus layer. Stratocumulus and cumulus tops average 5,000 feet (1,525 meters); cumulonimbus tops reach up to 50,000 feet (15.25km). Visibilities range from 3 to 7 miles (4.8 to 12 km) in fog and light rain, but may lower to 0.25 mile (400 meters) in heavy showers.

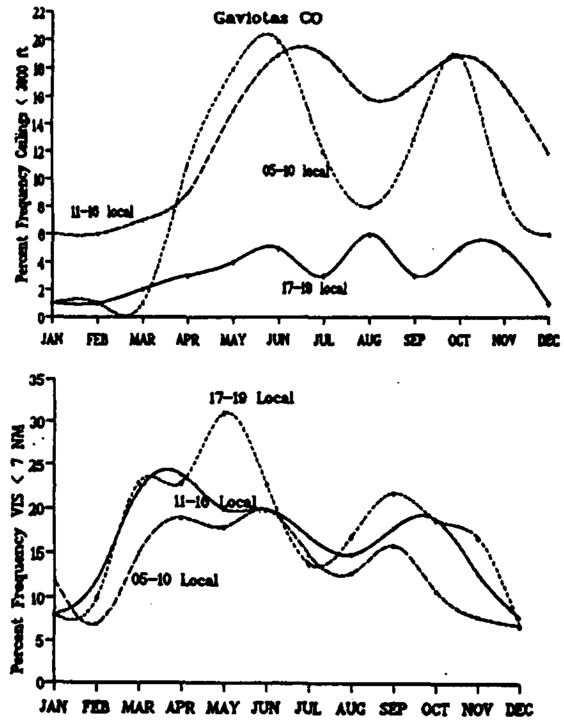


Figure 5-62. Percent Frequency Ceiling and Visibility <3,000/7: Gaviotas, Colombia.

WINDS. As the southeast trades set in, gradient flow changes from east-northeasterly at 10 to 15 knots to east-southeasterly at 10 to 15 knots. Actual surface flow varies according to terrain.

THUNDERSTORMS increase in frequency and intensity as the Monsoon Trough becomes established. They are also enhanced in mesoscale convective complexes.

PRECIPITATION. As shown in Figure 5-63, transition rainfall ranges from 7.9 inches (200 mm) in the southeastern Highlands to just over 4 inches (100 mm) along the northeastern Venezuela border.

TEMPERATURE. Highs range from 84 to 90°F (29 to 32°C); lows from 72 to 77°F (22 to 24°C). Temperatures have reached over 100°F (39°C) just before the onset of the wet season in the northern Colombian Highlands.

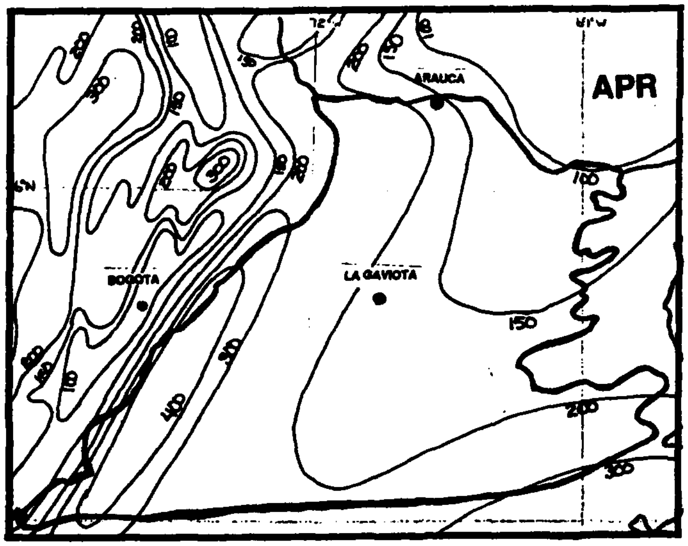


Figure 5-63. Mean Precipitation: April.

GENERAL WEATHER. The well-defined Colombian Highland wet season runs from May through November; the end of the season progresses from north to south during late November. Note that the wet season occurs in summer--typical of the tropical northern hemisphere. The proximity of the Monsoon Trough, combined with upslope flow, results in only one rainfall maximum, in June. The Monsoon Trough normally lies north of the Colombian Highlands along the southern slopes of the Venezuelan Andes. However, in years with abnormally strong southern hemisphere high pressure, or unusually low northern hemisphere high pressure, the Trough may cross the Venezuelan Andes to lie along the Caribbean Coast. In these cases, it is far enough northward to allow a slight precipitation decrease in late June and early July. Trough movement lags the solar cycle by 2 to 3 months.

Upper-level winds (see Figure 5-64) throughout this region are predominantly easterly. The 10,000-foot (3,050-meter) winds reflect the northeasterly trades as they push into the area during northern hemisphere winter. The 30,000-foot (9.2-km) winds show the formation and movement of the Bolivian upper air anticyclone during southern hemisphere summer.

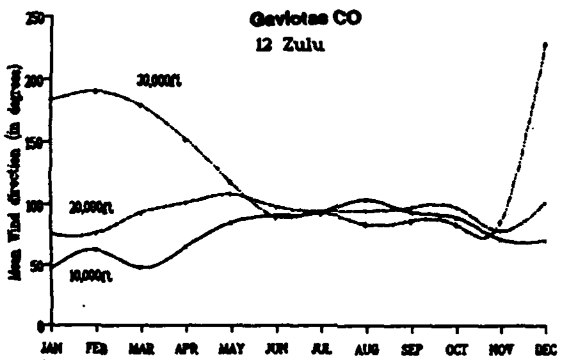


Figure 5-64. Mean 12Z Upper-Level Winds: Gaviotas, Colombia.

Strong southern hemisphere polar surges occasionally penetrate the Colombian Highlands. If they are strong enough, they displace the Monsoon Trough to the Caribbean coast. In extreme cases, these surges move into the extreme southern Caribbean. Their effects in the Highlands are to briefly stabilize the air and drop temperatures into the low 50s (°F) or high 40s (13 to 9°C). A minor decrease in precipitation occurs in July and August during those years in which there are strong outbreaks. The northward progression of an exceptionally strong Antarctic outbreak in mid-July 1975 is shown in Figure 5-65.

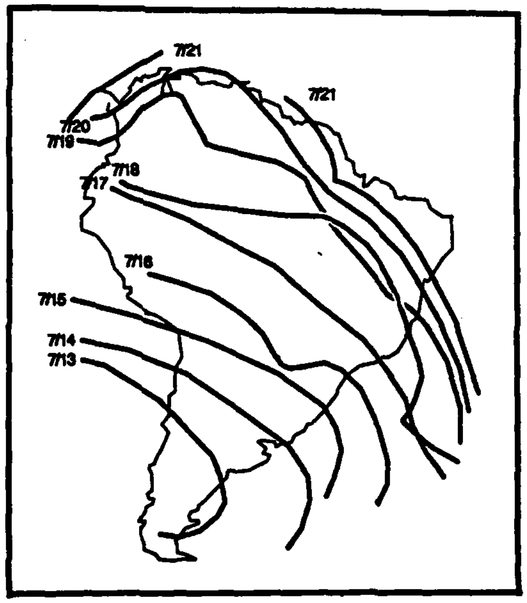


Figure 5-65. "Cold Surge" Continuity: 13-21 July 1975.

SKY COVER. Patchy early morning stratus with bases below 500 feet (150 meters) forms in river valleys at elevations up to 2,000 feet (610 meters). Fog may or may not occur underneath this stratus depending on precipitation. Otherwise, only scattered altocumulus/altostratus or cirrostratus occurs. By 1000 LST, the stratus has dissipated and heavy cumulus begins to form near 3,500 feet (1,070 meters). By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region. Tops vary from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST scattered thunderstorms form, dissipating after sunset; there are showers by late evening. Patchy river stratus forms after midnight.

Worse conditions occur with mesoscale convective complexes in the Monsoon Trough; 4-7/10 stratus with

bases at 300 to 500 feet (90 to 150 meters) and tops at 1,500 to 2,500 feet (450 to 760 meters) forms underneath stratocumulus/cumulus with bases at 2,000 to 2,500 feet (610 to 760 meters). Isolated cumulonimbus are embedded in this cumulus/stratocumulus layer. Stratocumulus/cumulus tops average 5,000 feet (1,525 meters), but cumulonimbus tops reach 50,000 feet (15.25km). Visibilities are from 3 to 7 miles (4.8 to 12 km) in fog and light rain, but may drop to 0.25 mile (400 meters) in heavy showers.

WINDS. Gradient flow is easterly to southeasterly at 10 to 15 knots, but actual surface flow is variable according to terrain. Winds may be stronger with thunderstorms.

THUNDERSTORMS. Widespread thunderstorm activity is a function of polar surges or mesoscale convective complexes, but scattered thunderstorms are found throughout the region. Most occur in the wet season. Severe thunderstorms are rare.

PRECIPITATION. Wet season rainfall (shown in Figure 5-66) ranges from 125 inches (3,175 mm) in the northeast to 165 inches (4,200 mm) in the southwest.

TEMPERATURES. Highs range from 84 to 86°F (29 to 31°C), lows from 70 to 75°F (21 to 23°C).

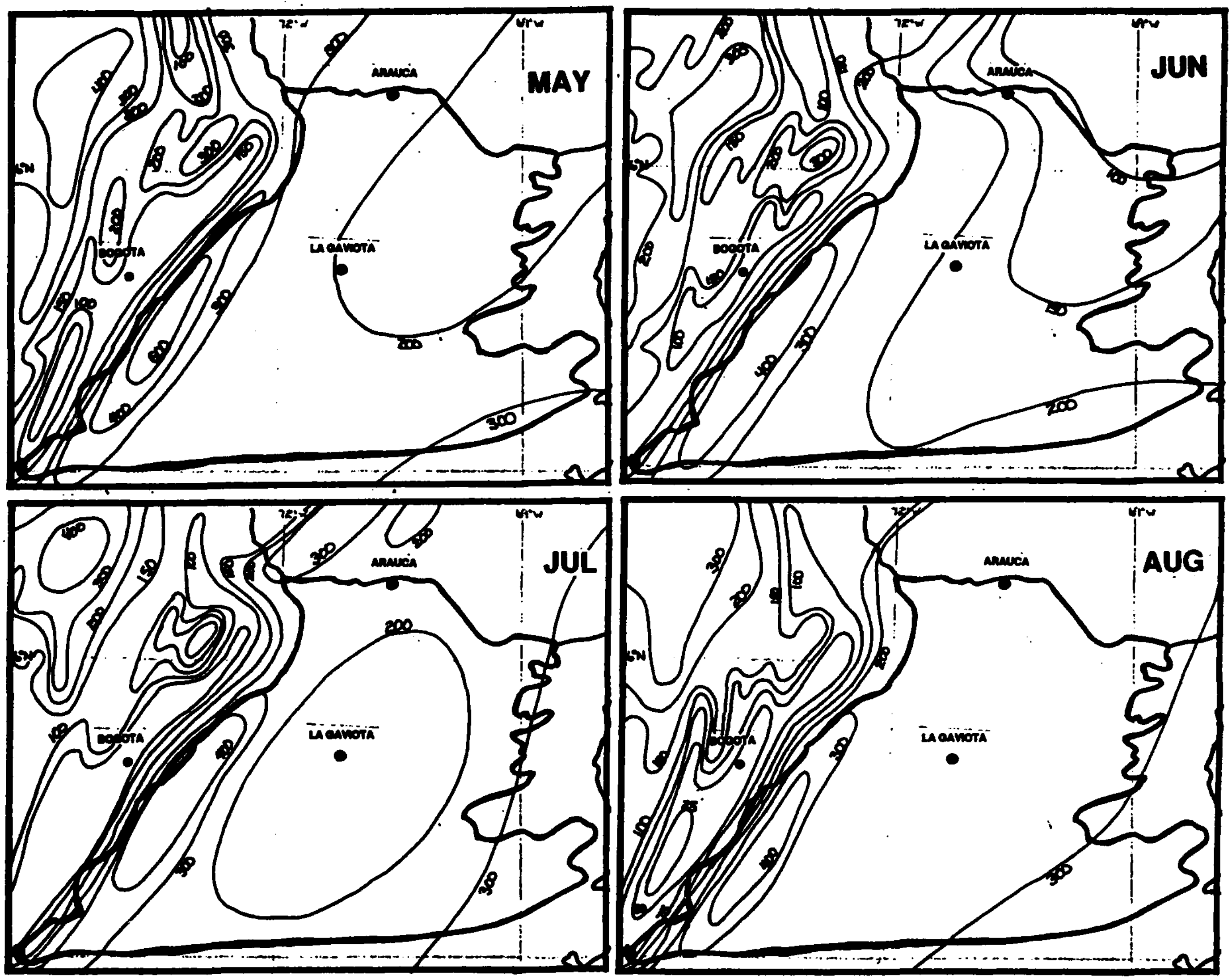


Figure 5-66. Mean Monthly Precipitation: May-August.

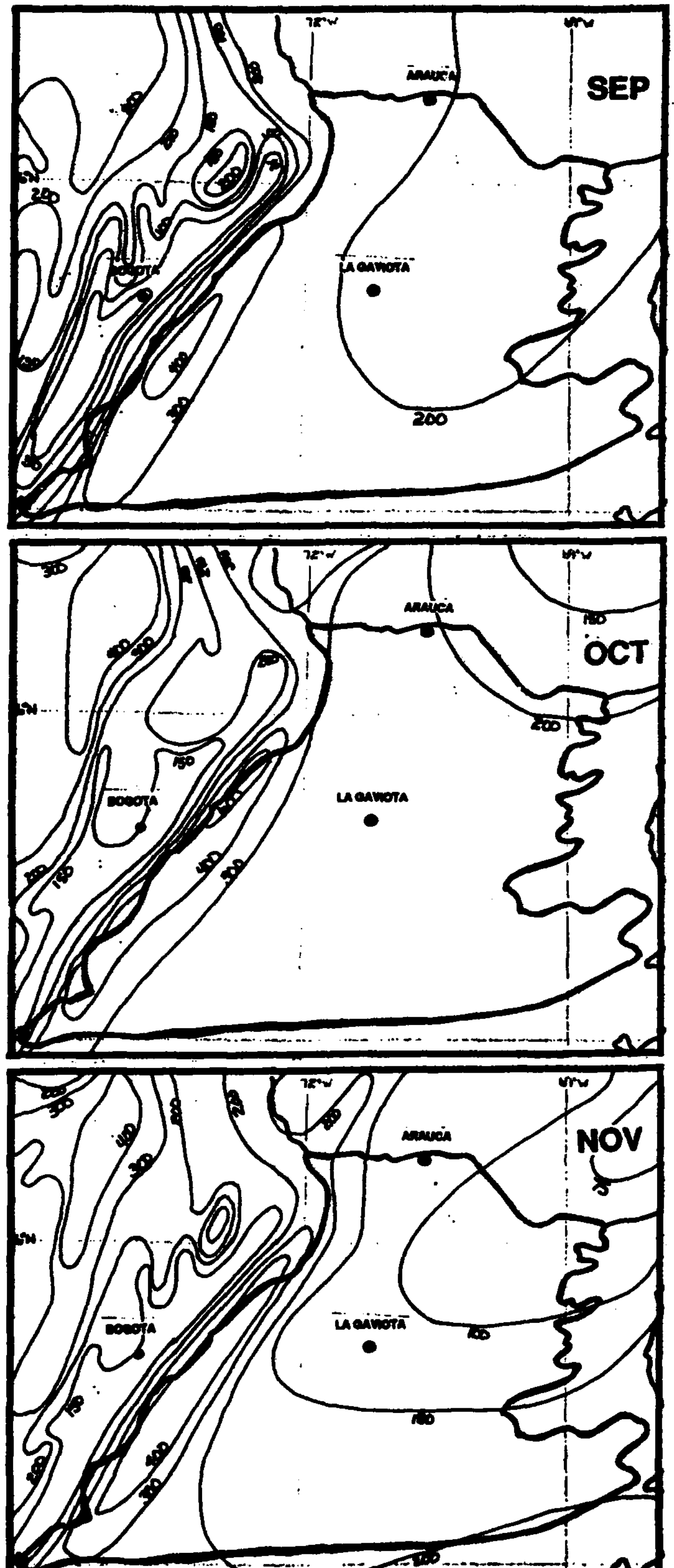


Figure 5-66, Cont'd. Mean Monthly Precipitation: September-November.

GENERAL WEATHER. The wet-to-dry transition, which takes place much earlier here than in the upper Orinoco Plains, varies from northeast to southwest. Northeastern portions of the Colombian Highlands see the wet season ending much earlier, while southern areas and the eastern sides of the southern Andes see only a letup in rainfall. Upslope flow in the south and east ensures continuation of the rains even though the Monsoon Trough retreats into the southern Amazon basin.

The southward movement of the Monsoon Trough does not, as in other areas, mark the end of the wet season here. The rainy season's end here must await increased subsidence in the northeast trades; this subsidence overrides the effects of the gradual upslope flow in the central and northern Highlands, but it does not normally occur until mid-November. Aiding this process is the steadily decreasing sun angle. Trough movement is known to lag the solar cycle by 2 to 3 months. The Monsoon Trough moves southward rapidly; precipitation and cloud cover lag its passage by nearly 2 months.

SKY COVER. In the subsiding air of the advancing northeasterly trade winds, patchy low stratus forms near dawn along rivers, dissipating by 0900 LST. Isolated cumulus forms by 1000 LST based at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset.

In the still unstable northeast trades to the north of the advancing Monsoon Trough, patchy early morning stratus forms in river valleys at elevations up to 2,000 feet (610 meters). Fog may or may not occur underneath this stratus depending on precipitation. Otherwise, only scattered altocumulus/altostratus or cirrostratus is present. By 1000 LST, the stratus dissipates. Heavy cumulus begins to form near 3,500 feet (1,070 meters). By 1200 LST, widespread towering cumulus and isolated cumulonimbus, with bases at 4,000 feet (1,220 meters), dot the region; tops are from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered thunderstorms occur, dissipating after sunset. There are showers by late evening. Patchy river stratus forms after midnight.

Worse conditions occur with mesoscale convective complexes in the Monsoon Trough; 4-7/10 stratus with bases at 300 to 500 feet (90 to 150 meters) and tops at 1,500 to 2,500 feet (450 to 760 meters) forms underneath stratocumulus/cumulus with bases at 2,000 to 2,500 feet (610 to 760 meters). Isolated cumulonimbus are embedded in the cumulus/stratocumulus layer. Stratocumulus/cumulus tops average 5,000 feet (1,525 meters), but cumulonimbus tops reach 50,000 feet (15.25 km). Visibilities range from 3 to 7 miles (4.8 to 12 km) in fog and light rain, but drop to 0.25 mile (400 meters) in heavy showers.

WINDS. As the northeast trades become established, gradient flow changes from east-southeasterly at 10 to 15 knots to east-northeasterly at 10 to 15 knots. Surface flow varies according to terrain.

THUNDERSTORMS. Thunderstorms are found in those areas still affected by the Monsoon Trough, and isolated storms can occur with mesoscale convective complexes.

PRECIPITATION. Rainfall during the transition varies from 11.8 inches (300 mm) in the southern Highlands to only 5.9 inches (150 mm) in the northeast.

TEMPERATURE. Temperature ranges increase as the transition ends. Highs now range from 84 to 90°F (29 to 32°C); lows from 70 to 75°F (21 to 23°C).

GENERAL WEATHER. The Colombian Highlands dry season begins in mid-to-late November--well after the Monsoon Trough's southward passage. Increased subsidence in the northeasterly trades is necessary to overcome the effects of cyclonic low-level, terrain-induced turning and forced (upslope) lift.

SKY COVER. Over that portion of the Highlands within 100 miles (160 km) of the eastern Andes, patchy low stratus forms near dawn in low-lying valleys, usually dissipating by 0900 LST. Scattered cumulus forms by 1000 LST with bases at 3,500 feet (1,070 meters). Scattered heavy cumulus and isolated cumulonimbus with tops from 15,000 to 30,000 feet (4.6 to 9.1 km) form by early afternoon. Scattered heavy showers occur throughout the afternoon and early evening. Clouds partially clear after sunset.

In the rest of the Highlands, patchy low stratus forms near dawn along the Orinoco River proper, dissipating by 0900 LST. Scattered cumulus forms by 1000 LST with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Heavy showers occur underneath towering cumulus. Clouds clear rapidly after sunset. Heavy cumulus and cumulonimbus can occur over the extreme southern Highlands in February and March as the Monsoon Trough starts to move northward.

WINDS. Gradient flow is northeasterly to east-northeasterly at 10 to 15 knots. Surface flow depends on terrain.

THUNDERSTORMS. Isolated thunderstorms occur within 100 miles (160 km) of the Andes due to increasing instability and forced lift.

PRECIPITATION. Rainfall ranges from 15.9 inches (405 mm) in the southwestern Highlands to only 4 inches (101 mm) in the northeastern portion. Mean monthly rainfall data for December through March is shown in Figure 5-67.

TEMPERATURE. Highs range from 86 to 94°F (30 to 34°C); minimums from 66 to 72°F (19 to 22°C). Temperatures in the central Orinoco Plains have reached 106°F (41°C).

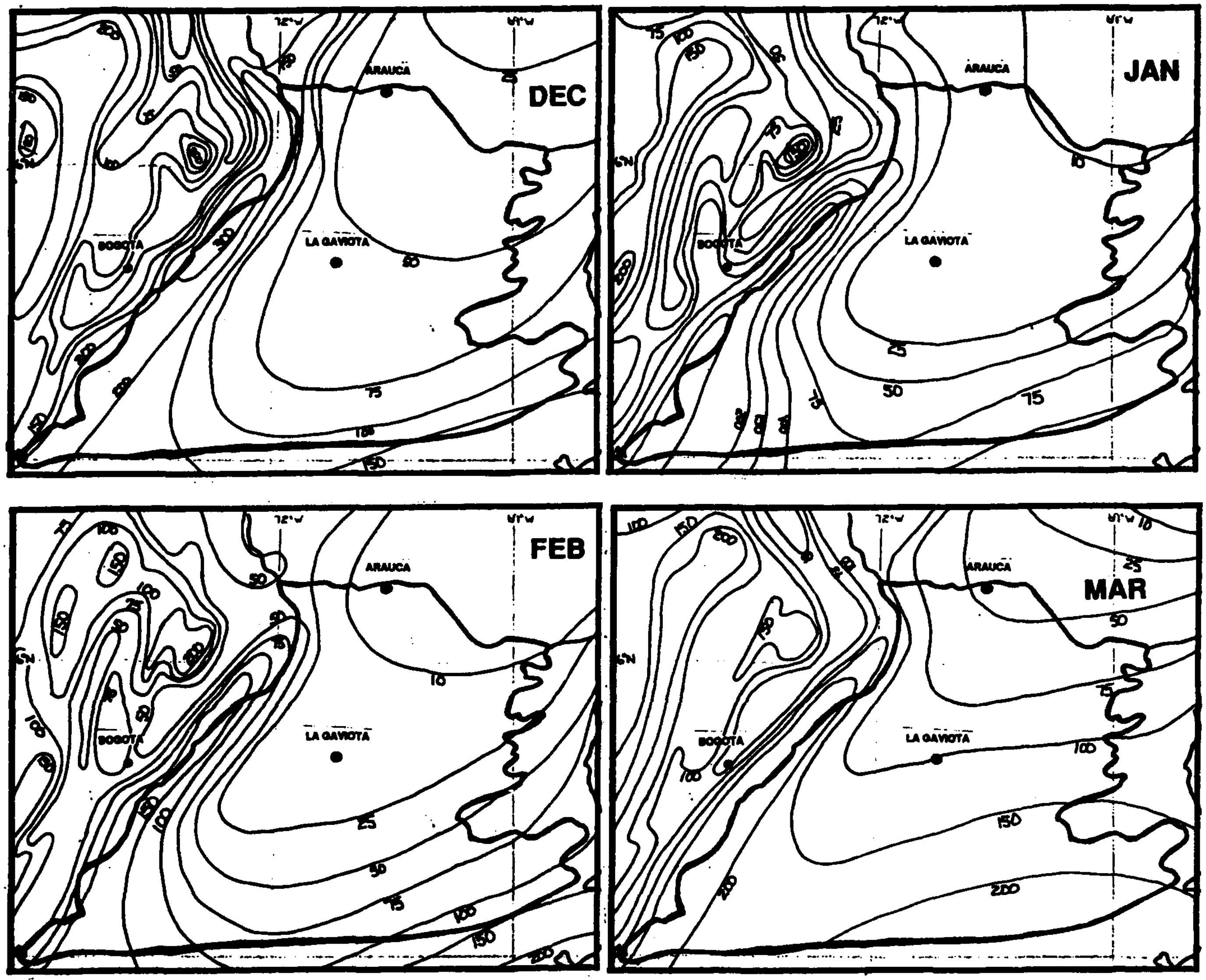


Figure 5-67. Mean Monthly Precipitation: December-March.

5.6 THE ORINOCO BASIN

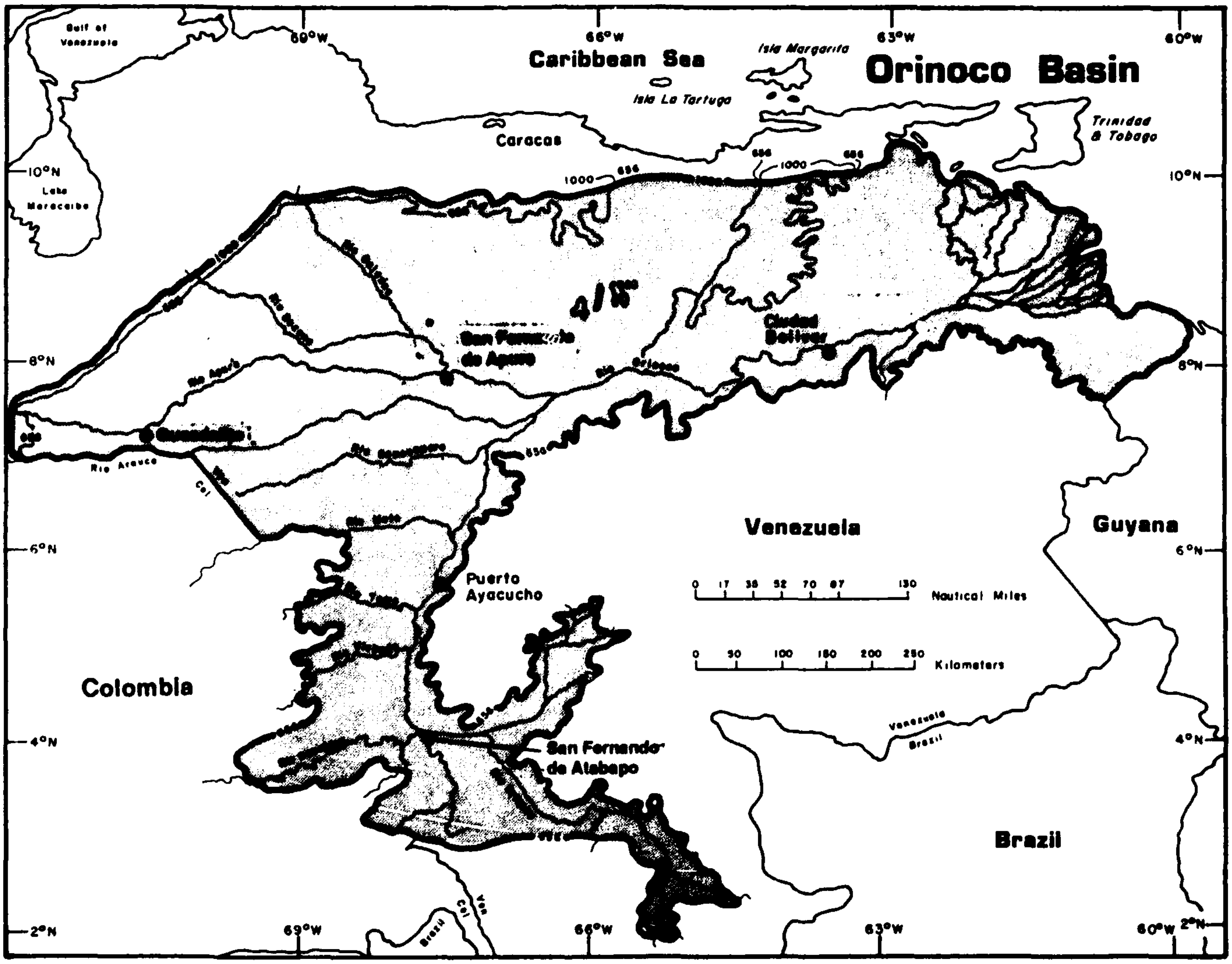


Figure 5-68. The Orinoco Basin. This region extends from extreme eastern and northeastern Colombia and southeastern Venezuela through central Venezuela to the Orinoco Delta.

ORINOCO BASIN GEOGRAPHY

BOUNDARIES. The region described here as the Orinoco Basin is bounded as follows:

On the south, along the 656-foot (200-meter) contour line from the coastal plains on the south side of the Orinoco Delta west and south along the northern and western side of the Guyana Highlands to its intersection with the Guyana Highlands (at approximately 2° 25' N, 65° W). Then west to the 656-foot (200-meter) contour line along the south side of the Orinoco drainage to the ridge separating the Orinoco and Amazon river drainages at 66° W. From this point westward to the Colombia-Venezuela border at 3° N.

On the west, northward along the Colombia-Venezuela border from 3° N to 4° N, then north along the west side of the Orinoco River to the Meta River (Rio Meta). Then westward along the Meta River to the Venezuela-Colombia border and northwestward along the frontier to the 1,000 foot-(305-meter) point.

On the north, eastward along the south side of the Turimiquire-Coastal mountains from the 1,000-foot (305-meter) point on the Venezuelan-Colombian border, gradually descending to the 656-foot (200-meter) contour line on the south side of the Turimiquire Mountains (Serrania de Turimiquire) in extreme northeastern Venezuela. Then eastward to the coastal plains on the north side of the Orinoco Delta.

On the east, by the Atlantic Ocean.

CLIMATIC PECULIARITIES. The upper Orinoco is a basin surrounded by mountains. There is no "dry" season, as such--only a period that is slightly drier than the wet season. Cloud cover, precipitation, winds, thunderstorms, and fog vary dramatically from ridge to valley, and complex mountain valley wind patterns further complicate weather and climate.

TERRAIN. *Terrain in southwestern, central and eastern* Venezuela consists of relatively flat plains with numerous tributaries flowing into the Orinoco. The southern Venezuelan and Colombian portions of the region change into cut-up plains as the elevation rises and the Orinoco tributaries fall over steeper gradients. Elevations range up to 1,640 feet (500 meters). Vegetation in eastern, central, and southwestern Venezuela, except along the Orinoco and its primary tributaries, is tropical savanna. The rest of the area is tropical rain forest.

From a point about 90 miles (145 km) inland from the Atlantic coast, numerous river "mouths" (called "passes" on the Mississippi River south of New Orleans) fan out from north-northwest through east to drain the Orinoco into the ocean. These mouths begin about 40 miles (65 km) downstream from Guyana City, located at the junction of the Caroni River and the Amazon. The area between these mouths consists of half-submerged swamp with isolated patches of lowland.

Land north and west of the Orinoco River, from the head of the delta west and south to the Vichada River (4° 55' N, 67° 50' W) consists mainly of gently rolling plains cut by numerous meandering tributaries of the Orinoco. As the land slopes gradually upward toward the eastern and southern slopes of the Andes, the tributaries, which include numerous streams and four major rivers, flow east and south. The rivers include the Apure, the Arauca, the Capanaparo, and the Meta. Two isolated hilly outcrops break these rolling plains. The first, centered near 8° 35' N, 68° 45' W, has a radius of about 25 miles (40 km). The second, centered near 9° N, 68° 10' W, has a radius of about 10 miles (16 km).

Land south of the Orinoco from the delta inland to Guyana City (Ciudad Guyana) consists of rolling hills with maximum elevations from 2,500 to 3,500 feet (760 to 1,065 meters).

West of the Caroni River, the Orinoco flows along the north, west, and eventually, southwest, sides of the Guyana Highlands, which are discussed separately. Two major rivers flow out of the Guyana Highlands into the Orinoco from the south and east: The Caura River flows north out of the central portion of the Highlands to join the Orinoco near 7° 40' N, 67° 55' W, and the Ventuari River flows westward from the western Highlands to reach the Orinoco at 4° N, 67° W. Land south and east of the Orinoco upstream of its junction with the Caroni rises rapidly in rugged hilly or mountainous terrain.

South of the Vichada River (and especially southeast of the Inirida River), terrain in the Orinoco Basin on both sides of the Orinoco River turns into true mountains.

Elevations rise rapidly southward to over 4,000 feet (1,220 meters) within 15 miles (25 km).

VEGETATION. A combination of evergreen swamp forest and mangrove trees that reach heights of 60 to 80 feet (18 to 24 meters) covers the Orinoco Delta. Mangroves are primarily found on extensive mud flats within 40 miles (65 km) of the coast. Little grows under the tree cover. On those land areas that have been cleared, marsh vegetation and swamp grass are common.

Land north and west of the Orinoco is primarily tropical savannah. This area constitutes the "llanos," or plains. Savannah vegetation is primarily coarse grass reaching heights of 3 to 5 feet (0.9 to 1.5 meters). Isolated evergreens and palm trees grow to 40 feet (12 meters). Areas immediately adjoining major tributaries and the Orinoco have single-tiered tropical forests with heights averaging 40-80 feet (12-24 meters). There is little undergrowth.

The hilly and mountainous regions fringing the Orinoco and its tributaries south of the Vichada River have three-tiered tropical forest. In the emergent tier are isolated trees reaching 150-175 feet (45 to 53 meters), but the dense main canopy is at 75 to 150 feet (23 to 45 meters). An understory tier has tops of 30 to 50 feet (9 to 15 meters). Shrubs and floor cover are scarce except where the main and understory tiers have been cleared.

Land south of the Orinoco to the north of the Ventuari River in extreme southwestern Venezuela is tropical savannah similar to that north of the Orinoco in the plains.

GENERAL WEATHER. The Monsoon Trough does not move steadily northward across the Guyana Highlands into the Orinoco Basin; instead, a "new" trough forms across the basin. As a result, the speed of the wet season's onset depends on synoptic scale influences. See Figure 5-69 for a graphic illustration of this phenomenon.

The rapid late April transition from the "dry" to the wet season progresses from southwest to the north. In the southern part of the region, monthly rainfall increases from the "dry" season's 7 inches (175 mm) to more than 12 inches (300 mm) in the wet season. But the transition in the northern half is more dramatic as the dry, semi-arid conditions there become heavy convective rains. Venezuelans term the wet season their "winter" and the dry season their "summer," even though the calendar says the opposite.

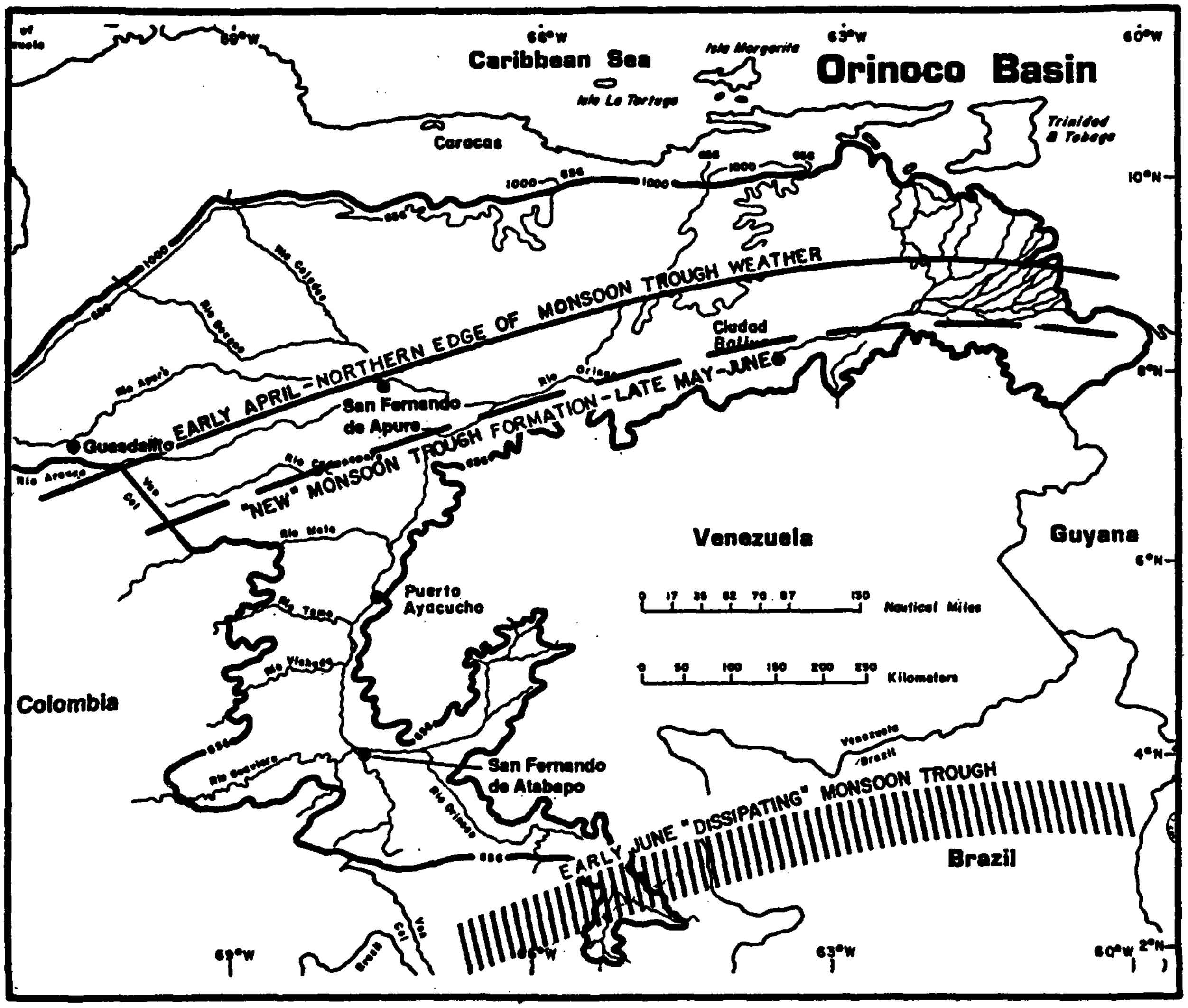


Figure 5-69. Low-Level Monsoon Trough Northward Transition.

SKY COVER. South of 5° N in the upper Orinoco, patchy valley stratus decks form by dawn, with tops to 2,500 feet (765 meters). Fog may or may not form under the stratus, depending on whether winds are upslope or downslope and whether or not precipitation is occurring. Above 2,500 feet (765 meters) skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus. Isolated heavy cumulus may be found along southeastern-facing ridges; tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 1000 LST, the stratus has dissipated, and heavy cumulus begins to form along mountain ridges and over flat-topped mesas above 3,500 feet (1,070 meters). By 1200 LST, most ridges and mesa tops see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2km). By 1400 LST, numerous thunderstorms occur, primarily over the surrounding mountains. Thunderstorms dissipate after sunset, but showers occur by late evening. Stratus forms in valleys after midnight. Figure 5-70 gives ceiling and visibility frequencies for Puerto Ayacucho, Venezuela, on the upper Orinoco at the Colombian border.

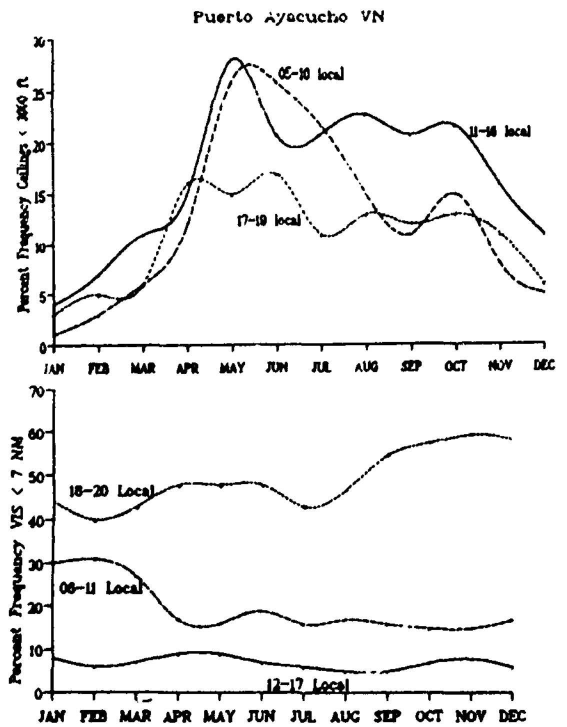


Figure 5-70. Percent Frequency Ceiling and Visibility<3,000/7: Puerto Ayacucho, Venezuela.

North of 5° N in the retreating northeasterly trade winds, patchy low stratus forms near dawn along the Orinoco River proper, dissipating by 0900 LST. Isolated cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset.

By the end of the transition, wet season conditions dominate the Orinoco Plains from the Colombian border eastward to the Orinoco Delta. In early morning, patchy river stratus forms with tops to 2,000 feet (610 meters). Fog may or may not occur under the stratus, depending on precipitation. Otherwise, there is only scattered altocumulus, altostratus, or cirrostratus. By 1000 LST, the stratus has dissipated and heavy cumulus begins to form near 3,500 feet. By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region. Tops vary from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered thunderstorms occur, dissipating after sunset. There are showers by late evening. Patchy river stratus forms after midnight. Figures 5-71 and 5-72, respectively, give ceiling and visibility data for Guasdualito, Venezuela, in the western Orinoco plains, and for San Fernando de Apure, in the central plains. Figure 5-73 gives summarized thunderstorm, precipitation, and temperature information for San Fernando de Apure.

Over the Delta, widespread low stratus forms by midnight, with bases from 500 to 1,000 feet (150 to 305 meters) and tops from 1,500 to 2,500 feet (455 to 760 meters). The stratus breaks up into cumulus by 0900 LST, and heavy cumulus begins to form near 3,500 feet. By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region; tops are from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, isolated thunderstorms occur, dissipating after sunset. There are showers by late evening. Patchy river stratus forms after midnight. Figure 5-74 gives ceiling and visibility data for Ciudad Bolivar--the nearest reliable reporting station to the Orinoco Delta.

Worse conditions--typical of the upper Orinoco--occur with mesoscale convective complexes in the Monsoon Trough.

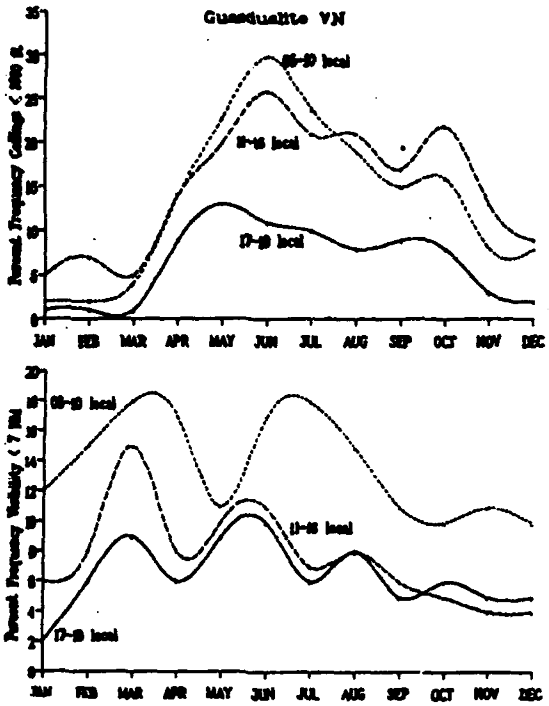
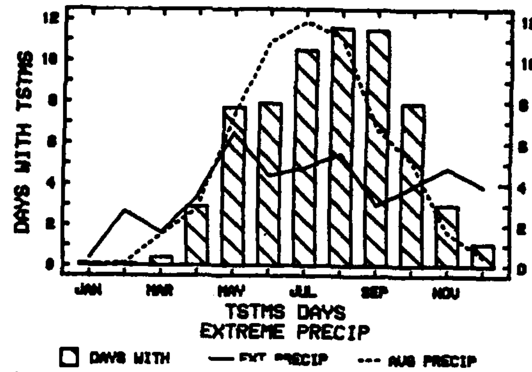


Figure 5-71. Percent Frequency Ceiling and Visibility <3,000/7: Guasdualito, Venezuela.



	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	24 HR PRECIP
JAN	100	88	64	.04	92	72	.1	.4
FEB	104	84	68	.15	95	73	.1	2.7
MAR	104	86	64	1.65	98	76	.4	1.6
APR	103	86	68	2.73	94	77	2.9	3.4
MAY	101	83	69	7.3	91	74	7.7	6.5
JUN	98	80	66	10.9	86	74	7.9	4.4
JUL	95	81	67	11.9	88	74	10.5	4.9
AUG	94	80	68	11.1	86	73	11.8	5.5
SEP	97	80	68	6.7	88	72	11.6	9
OCT	97	82	67	5.1	89	75	7.9	3.9
NOV	97	82	68	1.65	92	73	3	4.8
DEC	97	82	67	.43	92	72	1.1	3.9

Figure 5-73. Thunderstorm Days, Precipitation, and Temperature: San Fernando de Apure, Venezuela.

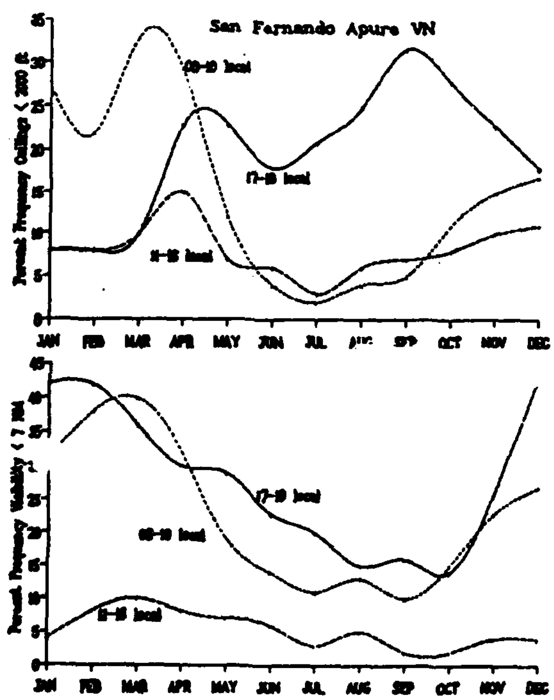


Figure 5-72. Percent Frequency Ceiling and Visibility <3,000/7: San Fernando de Apure, Venezuela.

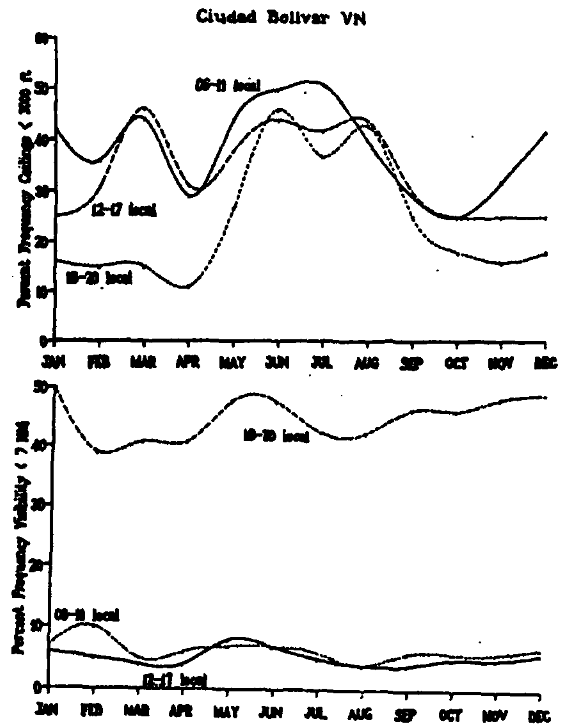


Figure 5-74. Percent Frequency Ceiling and Visibility<3,000/7: Ciudad Bolivar, Venezuela.

WINDS. As the southeast trades set in, gradient flow changes from east-northeasterly at 10 to 15 knots to east-southeasterly at 10 to 15 knots. Surface flow depends on terrain.

THUNDERSTORMS increase in frequency and intensity as the Monsoon Trough becomes established. They are enhanced in mesoscale convective complexes.

PRECIPITATION. Monthly rainfall ranges from 7.9 inches (200 mm) in the upper Orinoco to just over 1 inch (30 mm) near the Delta. April Orinoco region precipitation data is shown in figure 5-75.

TEMPERATURE. Highs range from 84 to 90°F (29 to 32°C); lows from 72 to 77°F (22 to 24°C). Temperatures have reached 102°F (40°C) just before the onset of the wet season in the central Orinoco Plains.

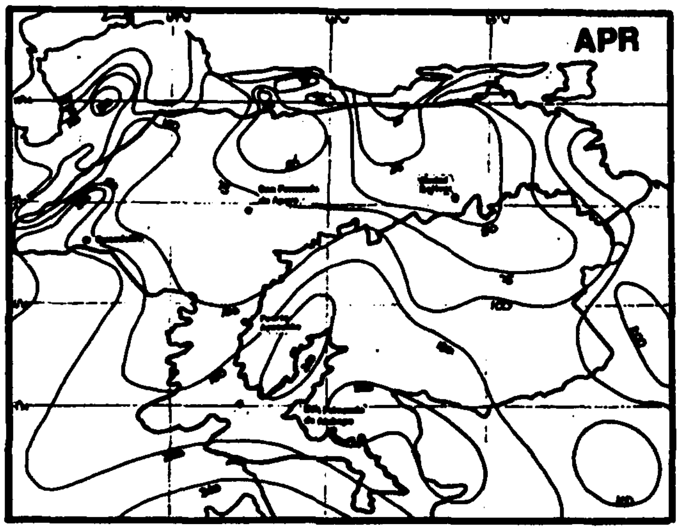


Figure 5-75. Mean Precipitation: April.

GENERAL WEATHER. On the central Orinoco Plains, a well-defined wet season runs from late April through September, while in the upper Orinoco, a longer wet season starts in late March and lasts til December. This is a tropical northern hemisphere precipitation distribution. The wet season here is the "summer."

The nearness of the Monsoon Trough results in only one precipitation maximum, in June. However, in years with abnormally strong southern hemisphere high pressure, or with unusually low northern hemisphere high pressure, the Trough may pass far enough to the north to allow a slight precipitation decrease in late June and early July.

In years when extremely strong southern hemisphere cold surges displace the Monsoon Trough northward into the extreme southern Caribbean, there is a brief increase in stability and a minor decrease in precipitation during July and August.

SKY COVER. Early morning sees patchy river stratus up to 2,000 feet (610 meters). Fog may or may not occur under the stratus depending on precipitation. Otherwise, only scattered altocumulus/altostratus or cirrostratus occurs. By 1000 LST the stratus has dissipated, and heavy cumulus begins to form near 3,500 feet (1,070 meters). By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region; tops are from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered thunderstorms occur, dissipating after sunset. There are showers by late evening. Patchy river stratus forms after midnight.

Trade wind surges, mesoscale convective complexes, and polar surges result in increased convection and produce the heaviest precipitation events of the wet season. Even during passages of these synoptic scale phenomena, precipitation frequencies are lowest from 0300 to 0900 LST. Widespread heavy towering cumulus and cumulonimbus occur over the entire region. Fragmentary reports suggest maximum daily precipitation in excess of 8.25 inches (210 mm). Actual amounts may be much higher.

WINDS. Gradient flow is easterly at 10 to 15 knots. Surface flow depends on terrain. Strong winds are rare.

THUNDERSTORMS. Scattered thunderstorms are found throughout the region. Widespread thunderstorm activity is a function of trade wind surges, polar surges or mesoscale convective complexes, most of which occur in the wet season. Severe thunderstorms are rare.

PRECIPITATION. Wet season rainfall ranges from 43 inches (1,100 mm) in the eastern Orinoco Basin to 63 inches (1,600 mm) in the upper Orinoco. Figure 5-76 gives mean monthly wet season rainfall amounts.

TEMPERATURE. Highs range from 84 to 86°F (29 to 31°C); lows from 72 to 77°F (22 to 24°C).

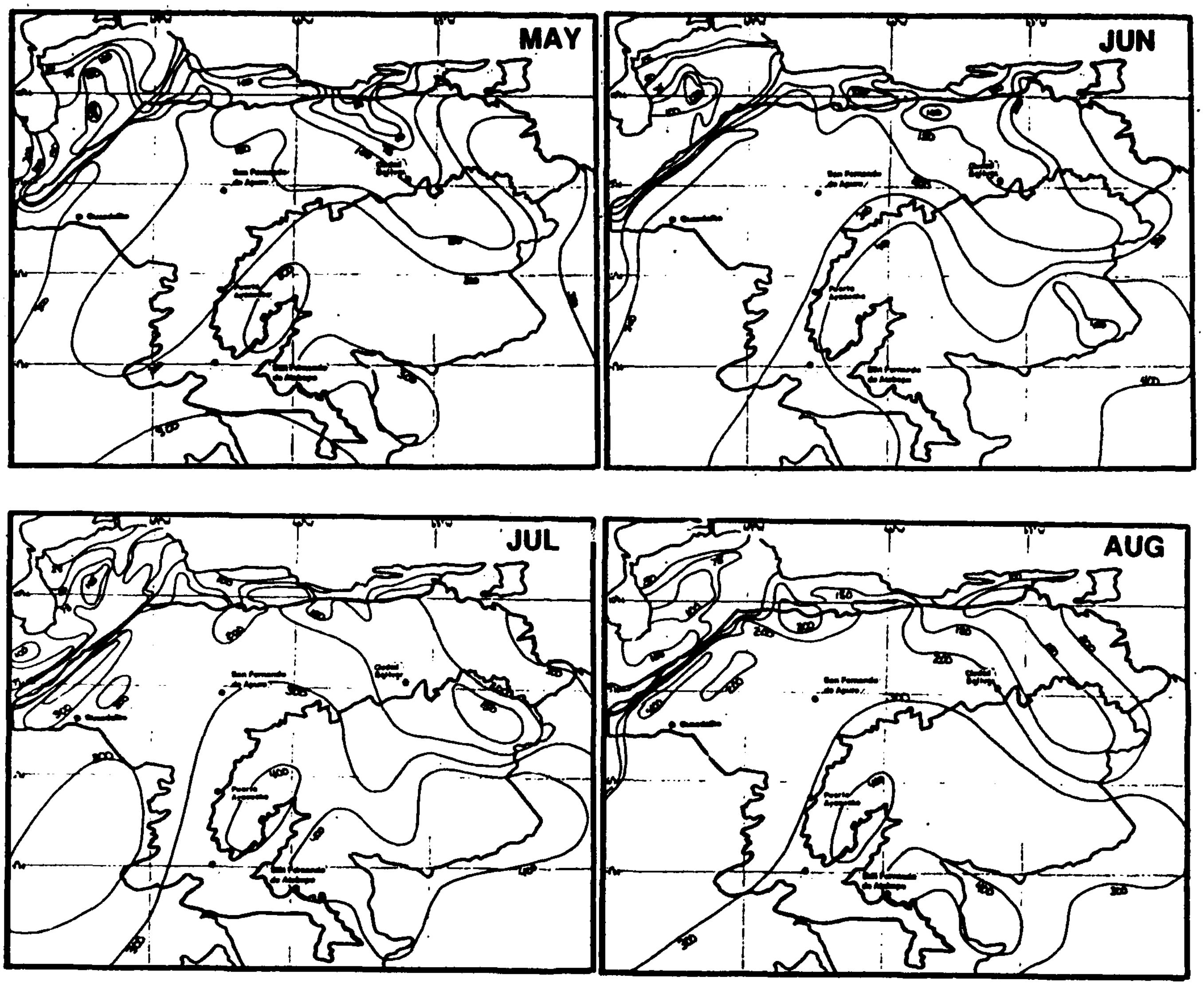


Figure 5-76. Mean Monthly Precipitation: May-August.

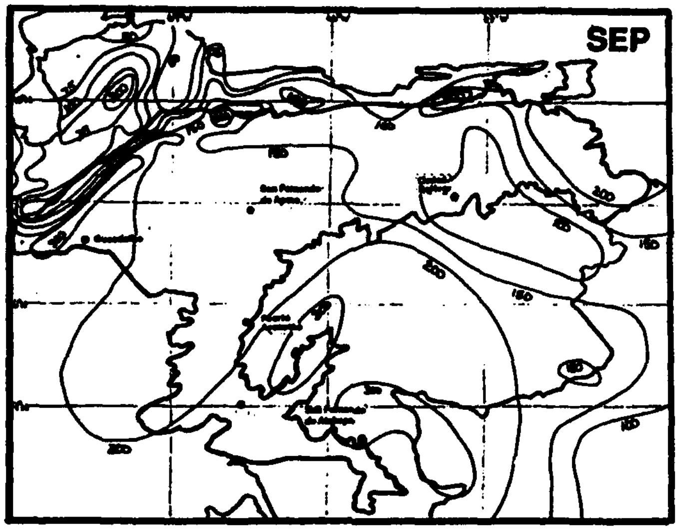


Figure 5-76, Cont'd. Mean Precipitation: September.

GENERAL WEATHER. In the central Orinoco Basin, the transition from wet to dry is from late September to early October. But in the upper Orinoco, due to surrounding mountains and longer exposure to the effects of the Monsoon Trough, the wet season persists into early December.

SKY COVER. In the immediate area of the dissipating Monsoon Trough and in the upper Orinoco, early morning sees patchy river stratus up to 2,000 feet (610 meters). Fog may or may not occur underneath the stratus depending on precipitation. Otherwise, only scattered altocumulus/altostratus or cirrostratus occurs. By 1000 LST, the stratus has dissipated, and heavy cumulus begins to form near 3,500 feet (1,070 meters). By 1200 LST, widespread towering cumulus and isolated cumulonimbus with bases at 4,000 feet (1,220 meters) dot the region. Tops vary from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, scattered thunderstorms occur, dissipating after sunset. There are showers by late evening. Patchy river stratus forms after midnight.

In the advancing northeasterly trade winds behind the Monsoon Trough, patchy low stratus forms near dawn along the Orinoco River proper, dissipating by 0900 LST. Isolated cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Trade wind surges bring typical wet season conditions to the Orinoco Delta, but these conditions normally dissipate rapidly 50 to 75 miles (80 to 120 km) inland.

WINDS. Gradient flow changes from east-southeasterly at 10 to 15 knots to east-northeasterly at 10 to 15 knots as the northeast trades set in. Surface flow depends on terrain.

THUNDERSTORMS. Thunderstorms are found in areas still affected by the Monsoon Trough. Isolated thunderstorms can result from trade wind surges in the Delta.

PRECIPITATION. Precipitation amounts vary from 5.9 inches (150 mm) in the southwestern Orinoco Basin, to 3.9 inches (100 mm) near the Delta. Upper Orinoco rainfall drops to slightly less than 6 inches (150 mm) by December. See Figure 5-77.

TEMPERATURE. Temperature ranges increase as the transition season ends. Highs now range from 84 to 90°F (29 to 32°C); lows from 70 to 75°F (21 to 23°C).

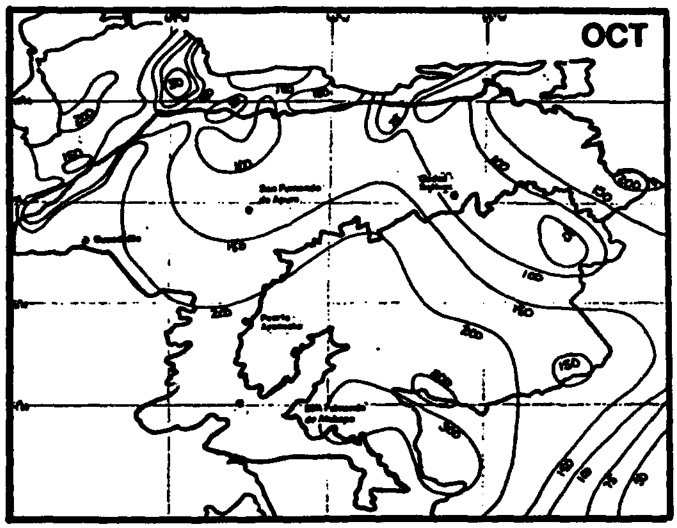


Figure 5-77. Mean Precipitation: October.

GENERAL WEATHER. The Orinoco Basin dry season begins in mid to late October--except for the upper Orinoco--and lasts to early April. Rainfall in the central and eastern Orinoco is extremely slight. Some locations in the central Orinoco Plains receive only a trace (1 mm) of precipitation during their driest month.

SKY COVER. In the upper Orinoco, patchy low stratus forms near dawn in low-lying valleys, dissipating by 0900 LST. Isolated cumulus forms over ridge lines by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Scattered heavy cumulus and isolated cumulonimbus with tops from 15,000 feet to 30,000 feet (4.6 to 9.1 km) form by early afternoon. Scattered heavy showers occur throughout the afternoon and early evening. Skies clear partially after sunset.

On the Orinoco Plains, patchy low stratus forms near dawn along the Orinoco River proper, dissipating by 0900 LST. Isolated cumulus forms by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Skies clear rapidly after sunset.

Worse conditions--typical of the upper Orinoco--occur over the Delta with trade wind surges.

WINDS. Gradient flow is northeasterly to east-northeasterly at 10 to 15 knots. Surface flow is variable during the night and early morning, becoming easterly at 5 to 10 knots in the afternoon. Winds in the upper Orinoco are variable depending on terrain.

THUNDERSTORMS. Isolated thunderstorms occur with trade wind surges over the Delta or with mesoscale convective complexes over the upper Orinoco.

PRECIPITATION. Wet season rainfall ranges from 4.1 inches (105 mm) in the central Orinoco Plains, to 20.6 inches (525 mm) in the upper Orinoco. See Figure 5-78.

TEMPERATURE. Highs range from 86 to 94°F (30 to 34°C); lows from 66 to 72°F (19 to 22°C). Temperatures in the central Orinoco Plains have reached 102°F (39°C).

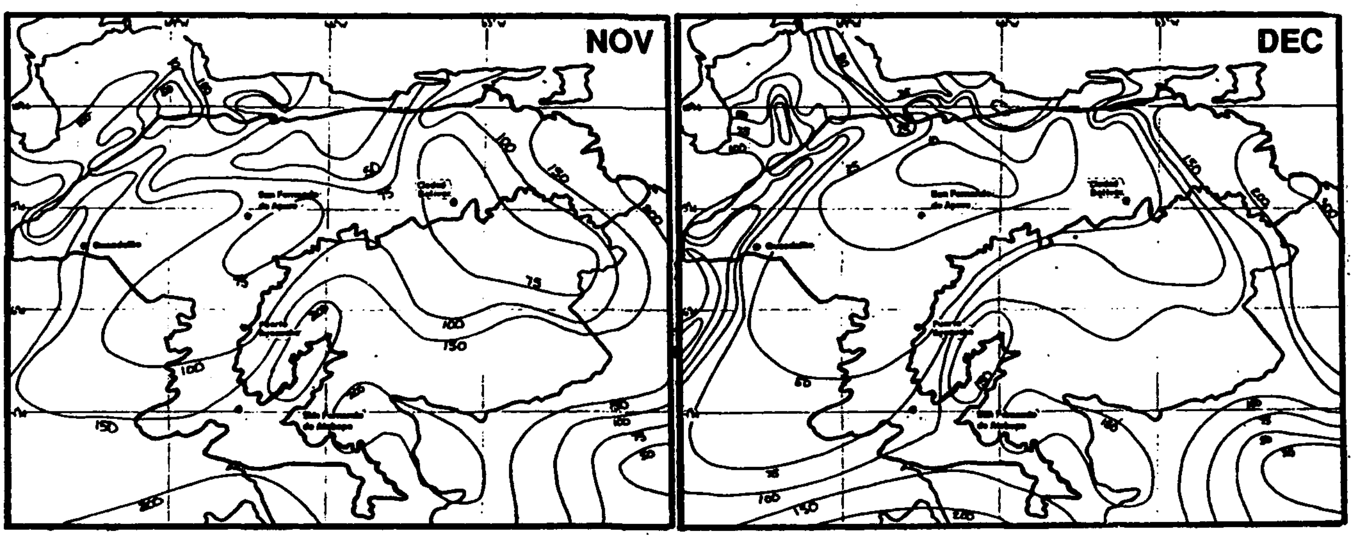


Figure 5-78. Mean Monthly Precipitation: November & December.

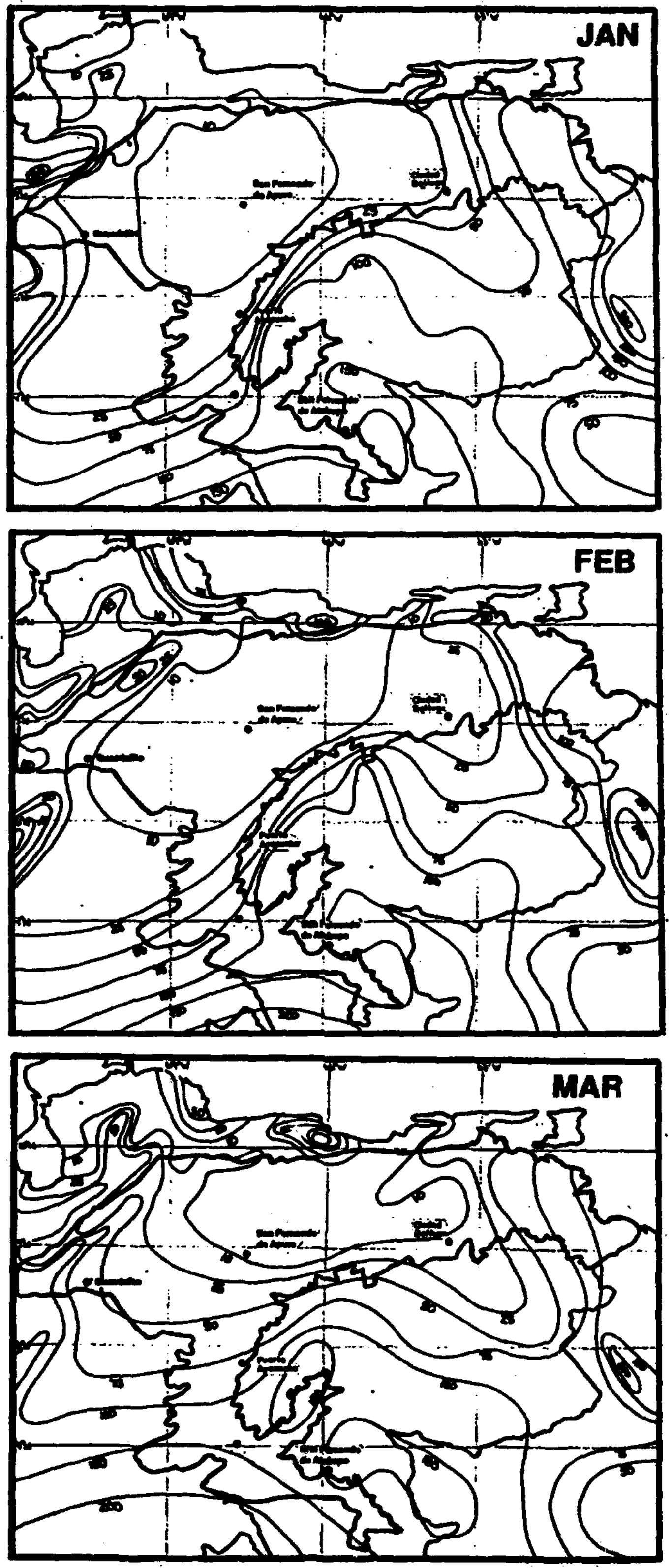


Figure 5-78, Cont'd. Mean Monthly Precipitation: January-March.

5.7 THE GUYANA COASTAL PLAINS

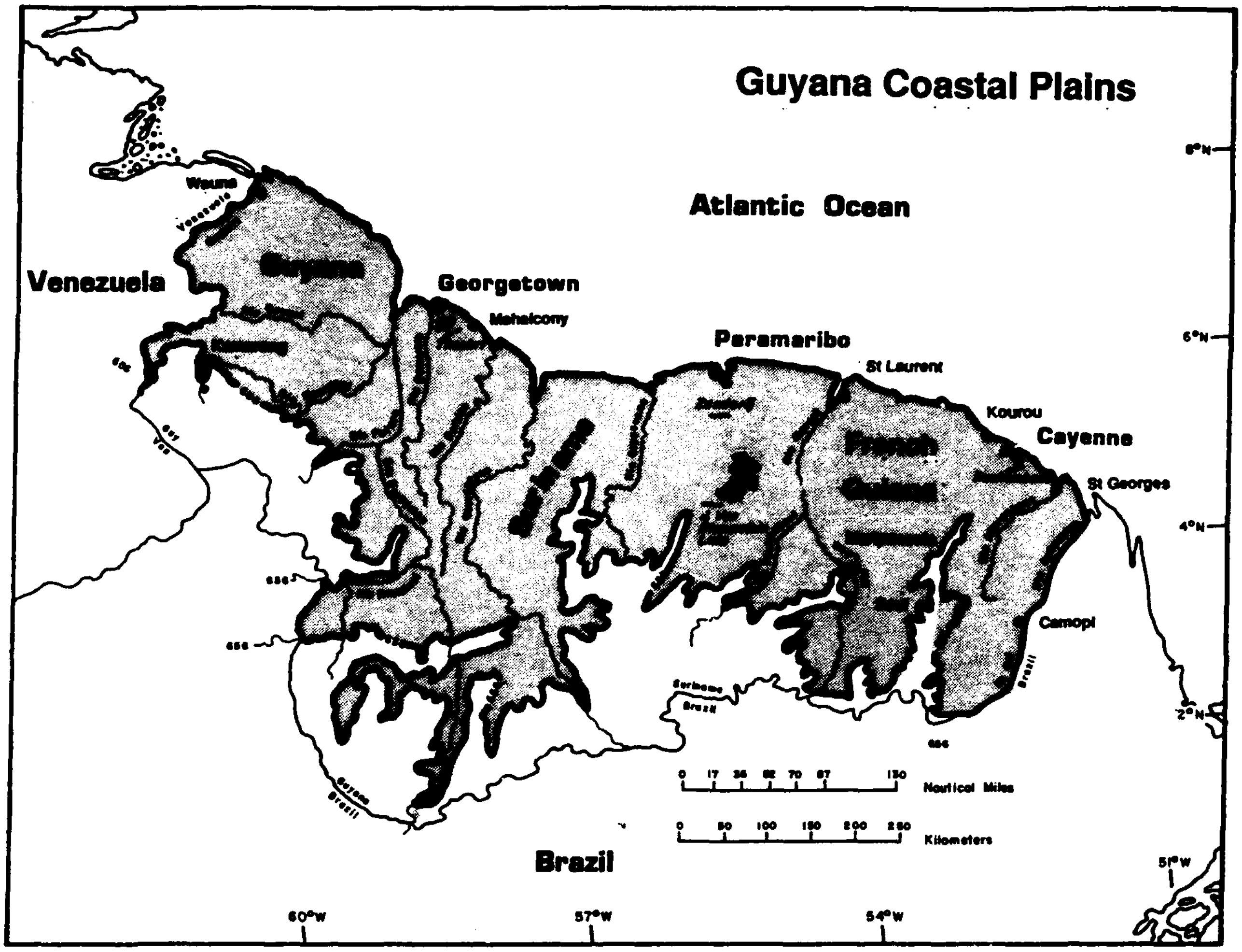


Figure 5-79. The Guyana Coastal Plains. The coastal plains extend inland from 20 to 80 miles (32 to 128 km). Elevations are less than 656 feet (200 meters). River deltas and much of the immediate coast consist of mangrove swamp. Inland vegetation is tropical rain forest.

GUYANA COASTAL PLAINS GEOGRAPHY

GENERAL. The interior of this region, especially in Suriname and Guyana, lacks the weather reporting stations necessary to define Monsoon Trough locations and movements there. The station network in French Guiana, however, extends far enough inland to provide reasonable Monsoon Trough locations. Extensive satellite imagery has been used to make up for surface station reporting deficiencies.

BOUNDARIES. The region described as the Guyana Coastal Plains is bounded on the south by the 656-foot (200-meter) contour line; on the west by the Orinoco Delta, on the north by the Atlantic Ocean, and on the east by the French Guiana-Brazil border.

TERRAIN. The coastal plains rise inland (south-southwestward). Width varies from 15-20 miles (24-32 km) at the eastern edge of French Guiana to 60-80 miles (96-130 km) in the center of Suriname. The plains narrow to 25 to 30 miles (40 to 48 km) at the Orinoco Delta. Terrain heights increase gradually south-southwestward. The plains are drained by numerous rivers, major examples of which rise in the Guyana Highlands.

There are three major rivers in French Guiana: the Oyapock divides Brazil from French Guiana, the Approuague is about 25 miles (40 km) west, and the Maroni forms the Suriname-French Guiana frontier.

In Suriname, the Maroni River is formed from two tributaries that join 85 miles (135 km) inland. The eastern tributary--the Awa River--forms the frontier; the western tributary is the Tapanahony. The Suriname River flows past Paramaribo (the capital). A dam at 5° S forms the J. Van Blommestein Lake--a 35 by 35 mile (55 by 55 km) rectangle. Halfway between Paramaribo and the Guyana frontier lies the Coppename River. Finally, the Courantyne River forms the border between Suriname and Guyana. Two dams along an old channel of the Courantyne form two elongated reservoirs; excess water is diverted to the west to form the Courantyne.

Also in Guyana, the Berbice River reaches the Atlantic 30 miles (45 km) west of the Courantyne. The Demerara, 50 miles (80 km) west of the Berbice, reaches the Atlantic at Georgetown (the capital). The mouth of the Essequibo system is 25 miles (40 km) west of Georgetown; this major river complex drains over 75% of Guyana and is formed by the merger of two tributaries (the Cuyuni and the Mazaruni), with the main stream 35 miles (55 km) inland. The Cuyuni, which forms the Guyana-Venezuela boundary in its upper reaches, flows in from the west; the Mazaruni, from the southwest. The Essequibo, by far the largest river system in Guyana, is joined by the Pataro at 5° 30' S and by the Rupununi at 4° S. The smaller Waini system enters the Atlantic 10 miles (16 km) from the Guyana-Venezuelan frontier.

VEGETATION. Mangrove swamp forest dominates the area from 20 to 25 miles (30 to 40 km) on either side of the mouths of named rivers. There are also mangrove swamps from the coast inland for 25 to 35 miles (40 to 55 km) in Suriname and Guyana east of Georgetown, and 10 to 20 NM inland in extreme northwestern Guyana. Other areas are covered by tropical rain forest.

GENERAL WEATHER. The Guyana Coastal Plain's well-defined wet season starts in late November or early December and lasts until mid-July or mid-August. But as one approaches French Guiana's Brazilian frontier, the wet season slowly shrinks to begin in January and end in June. In the Guyana Highlands (which see), there is an entirely different wet season-- one more typical of the northern hemisphere.

Circulation around the Azores High provides the northeasterly trades, the occasional trade wind surge, and even the rare northern hemisphere polar incursion. By January, the high is at its southernmost point and northeasterly trade winds entering the Guyanas are at their strongest. These winds, even those that began as North American polar air outbreaks, are warm, moist, and unstable. These characteristics combine with low-level convergence and heating to result in widespread rains. Figure 5-80 gives mean trade wind inversion heights through April, when the northeast trades are at their strongest.

Figures 5-81 and 5-82 give mean monthly upper-level wind directions over Cayenne, French Guiana, and Paramaribo, Suriname. Note that while low-level flow over Cayenne remains easterly, it is northeasterly over Suriname.

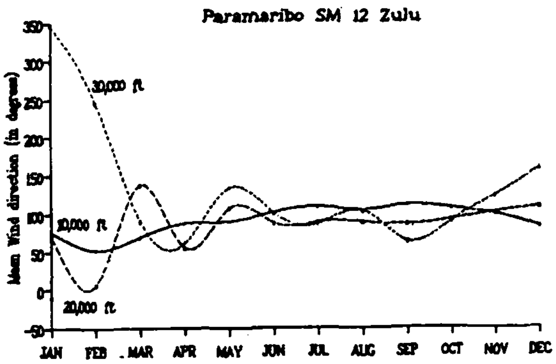


Figure 5-81. Mean 12Z Upper-Level Wind Directions: Paramaribo, Suriname.

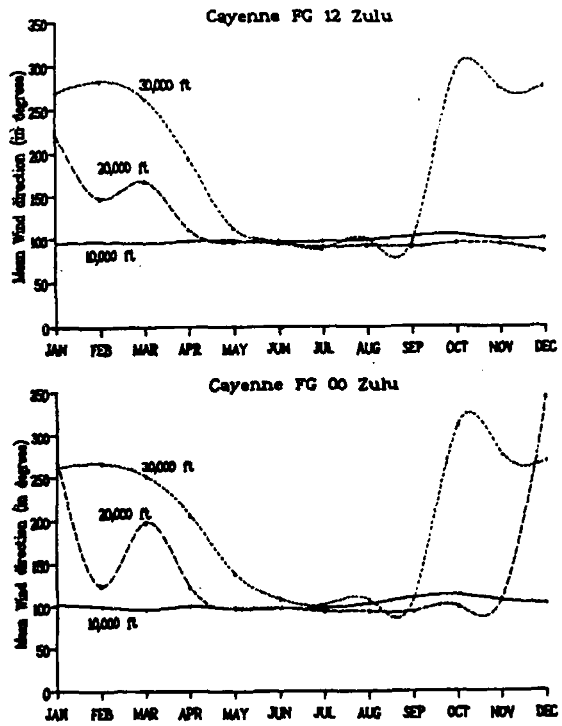


Figure 5-82. Mean Upper Level Wind Directions: Cayenne, French Guiana.

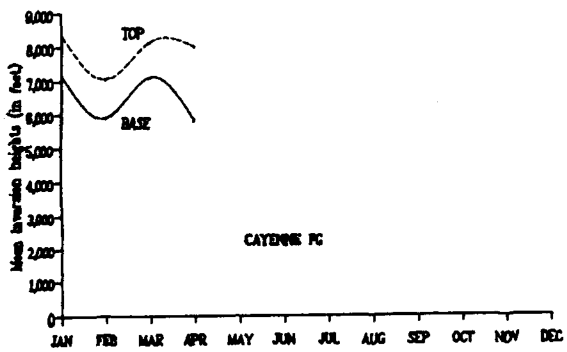


Figure 5-80. Mean Trade Wind Inversion Heights: Cayenne, French Guiana.

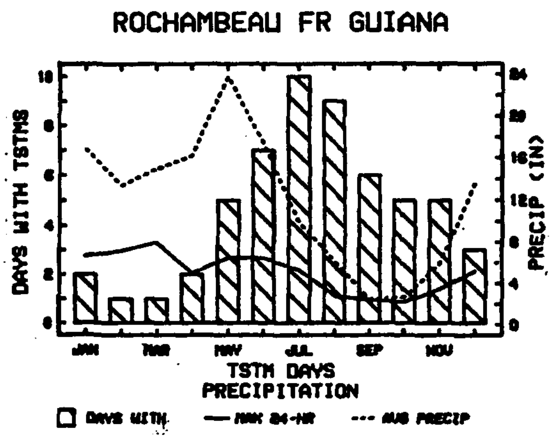
SKY COVER. During the beginning and ending of the wet season, the immediate coast to 10 miles (16 km) inland sees 5-7/10 low cloud cover from 300 to 500 feet (90 to 150 meters) in layers up to 2,500 feet (800 meters). There is also multilayered overcast altocumulus/altostratus with bases at 3,300 feet (1,000 meters) and tops to 14-16,000 feet (4,200 to 4,900 meters). Visibilities average 0.6 to 1.25 miles (1 to 2 km) in rain and rainshowers. Thunderstorms--some strong--occur over the entire region. The worst weather (and most thunderstorms) occurs in the afternoon as "rainy spells" separated by 1- to 3-day periods of weather similar to that of the "little summer," which see.

Multilayered overcast altocumulus/altostratus with bases at 10,000 feet (3,000 meters) and tops at 14,000 feet (4,200 meters) overlies banks of stratus and stratocumulus with bases at 1,000 feet (300 meters) and tops at 5,000 feet (1,500 meters). Visibilities range from 3 to 7 miles (6 to 10 km) in light to moderate intermittent rain. Thunderstorms occur along the southern edge of the Monsoon Trough. Fog is common at sunrise, but dissipates near 0700 LST.

The appearance of the "little summer" in late February and March depends on the southward displacement of the Monsoon Trough. If and when a "little summer" occurs, it is accompanied by patchy fair weather cumulus with bases at 2,500 feet (800 meters) and tops at 4,000 feet (1200 meters), beneath scattered altocumulus/altostratus and cirrus/cirrostratus. Visibility is fair to good, with haze. Fog occasionally forms near rivers and in low-lying areas after midnight, clearing rapidly after sunrise. Thunderstorms do not occur in the "little summer"; rain showers are widely scattered and light.

Conditions are generally typical of the height of the wet season, with trade wind surges, easterly waves, and polar surges. Ceilings lower to 300 to 500 feet (90 to 150 meters) with multilayered altocumulus/altostratus and embedded heavy towering cumulus and cumulonimbus. Visibilities are 2-4 miles (3-6 km) in rain, dropping to 0.5 mile or less (0.8 km or less) in showers and thundershowers. These conditions normally only last for 12 to 18 hours.

See Figures 5-83 through 5-92 for mean monthly summarized conditions at various selected stations throughout this region.



ROCHAMBEAU FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	91	77	66	16.6	82	73	2	6.7
FEB	90	77	65	13.4	82	73	1	7.2
MAR	93	78	67	15	83	73	1	8
APR	92	78	68	16.2	84	74	2	5
MAY	93	81	68	23.8	85	75	5	6.5
JUN	93	82	71	17.6	87	77	7	6.5
JUL	93	82	69	9.9	87	78	10	5.3
AUG	94	82	70	6.2	87	78	9	2.8
SEP	96	83	71	2.5	87	77	6	2.4
OCT	96	82	68	2.7	87	77	5	2.2
NOV	93	80	68	5.3	85	76	5	3.5
DEC	89	78	66	13.5	82	74	3	5.2

Figure 5-83. Thunderstorm Days, Precipitation, and Temperature: Rochambeau (Cayenne) French Guiana.

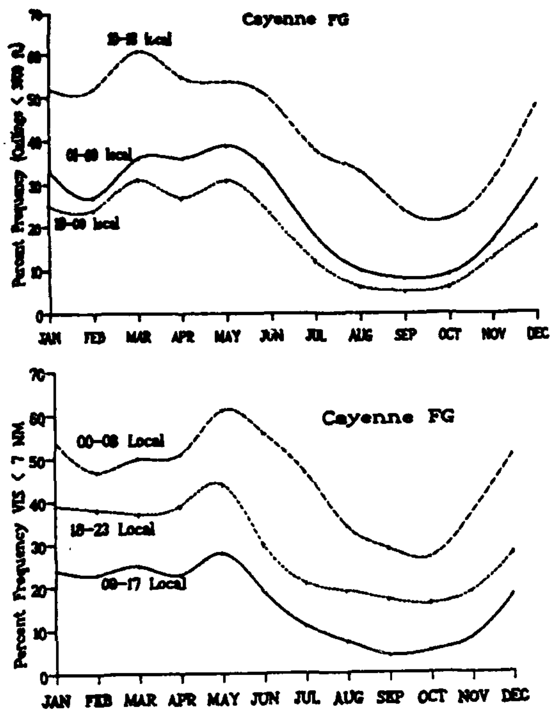


Figure 5-84. Percent Frequency Ceiling and Visibility < 3,000/7: Cayenne, French Guiana.

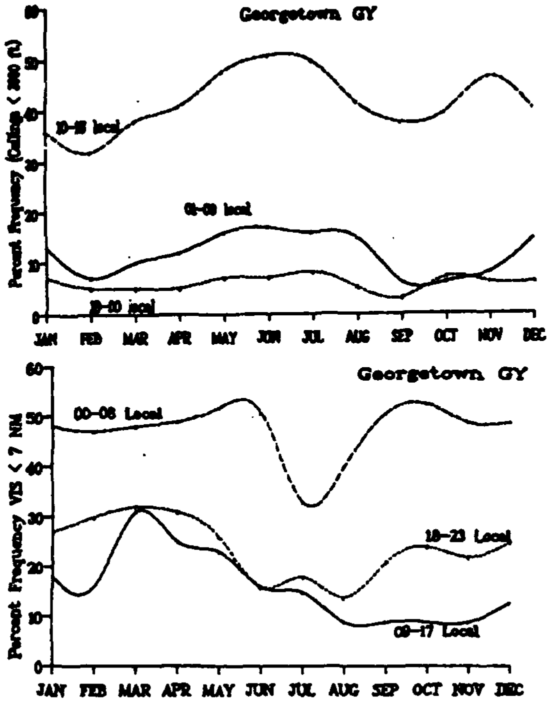


Figure 5-86. Percent Frequency Ceiling and Visibility: Georgetown, Guyana.

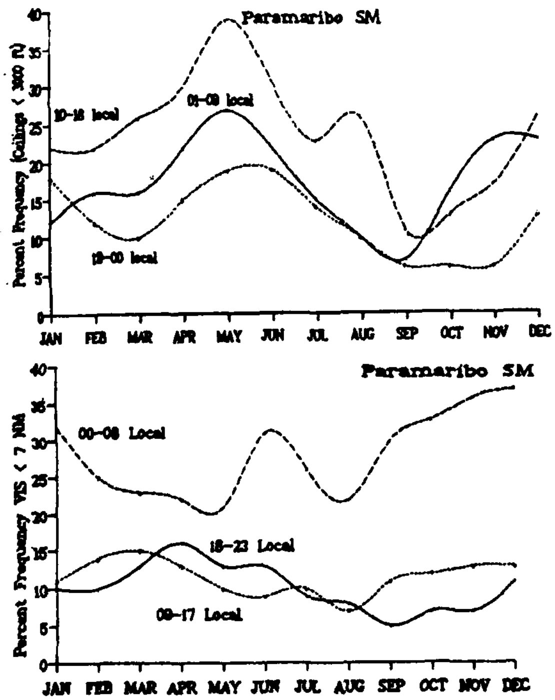
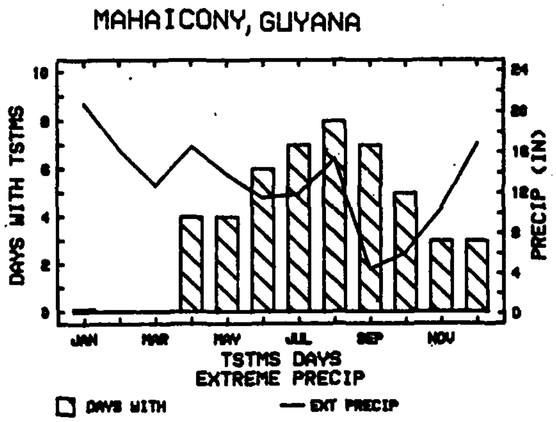


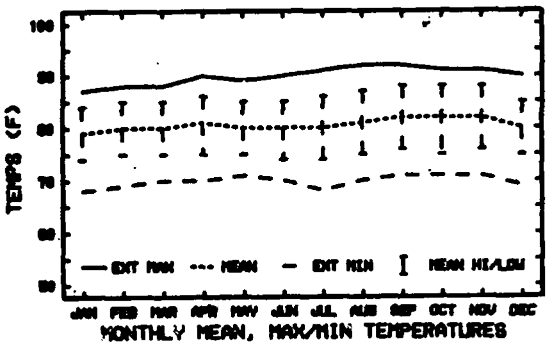
Figure 5-85. Percent Frequency Ceiling and Visibility <3,000/7: Paramaribo, Suriname.



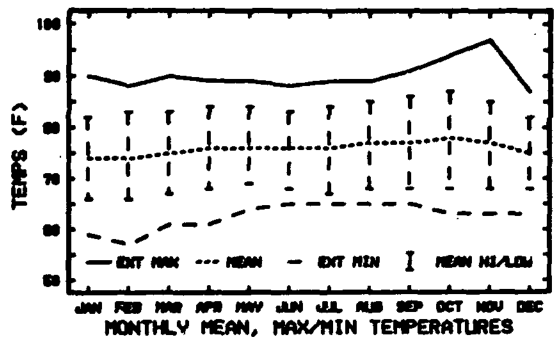
	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN
JAN	86	79	68	7.7	89	74
FEB	86	79	69	4.7	88	75
MAR	87	79	70	4.4	84	75
APR	88	80	70	8.2	86	76
MAY	87	80	71	11.2	84	76
JUN	88	80	70	8.17	86	75
JUL	89	80	68	9.4	86	75
AUG	89	81	69	6.8	86	77
SEP	90	82	72	2.61	87	76
OCT	90	82	71	3.1	87	76
NOV	91	81	70	5	87	76
DEC	89	80	71	9.5	84	75

Figure 5-87. Thunderstorms, Precipitation, and Temperature: Mahaicony, Guyana.

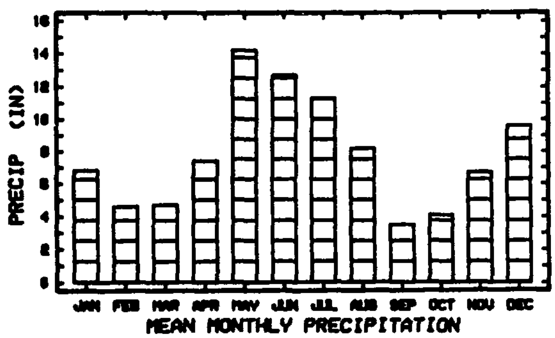
.GEORGETOWN, GUYANA



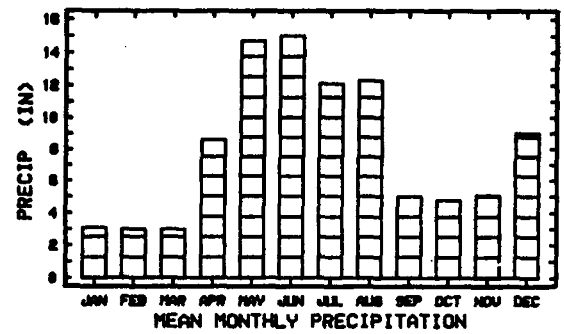
KAMARANG, GUYANA



GEORGETOWN, GUYANA



KAMARANG, GUYANA



GEORGETOWN, GUYANA

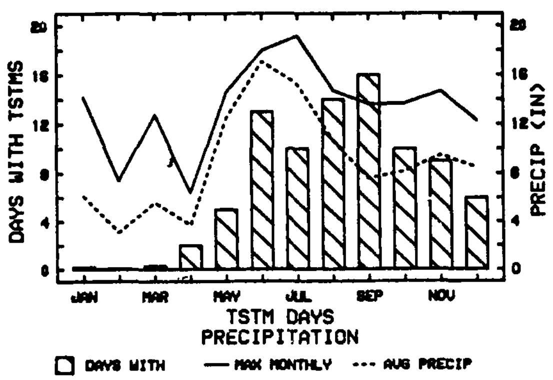
	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN
JAN	87	79	68	6.8	84	74
FEB	88	80	69	4.6	85	75
MAR	88	80	70	4.7	85	75
APR	90	81	70	7.4	86	75
MAY	89	80	71	14.2	85	75
JUN	90	80	70	12.7	85	74
JUL	91	80	68	11.3	86	74
AUG	92	81	70	8.2	87	75
SEP	92	82	71	3.5	88	76
OCT	91	82	71	4.1	88	75
NOV	91	82	71	6.7	88	76
DEC	90	80	69	9.6	85	75

Figure 5-88. Temperature and Precipitation: Georgetown, Guyana.

KAMARANG, GUYANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN
JAN	90	74	59	3.1	82	66
FEB	88	74	57	3	83	66
MAR	90	76	61	3	83	67
APR	89	76	61	8.6	84	68
MAY	88	76	64	14.7	84	69
JUN	88	76	65	15	83	68
JUL	89	76	65	12.1	84	67
AUG	89	77	65	12.3	85	68
SEP	91	77	66	5	86	68
OCT	94	78	68	4.8	87	68
NOV	97	77	63	5.1	85	68
DEC	87	76	63	9	82	68

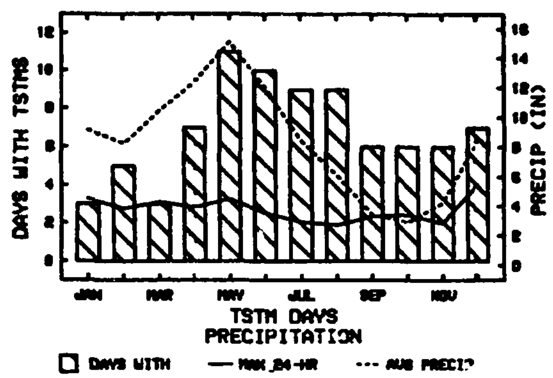
Figure 5-89. Temperature and Precipitation: Kamarang, Guyana.



WAUNA GUYANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX MON PRECIP
JAN	90	76	61	6.1	89	62	.2	14.2
FEB	91	77	62	8.1	91	63	.1	7.4
MAR	90	77	63	5.6	91	60	.3	12.8
APR	91	78	63	9.7	92	63	2	6.4
MAY	93	78	67	12.5	91	66	5	14.6
JUN	91	78	68	17.1	89	69	18	18
JUL	91	78	68	15.2	90	66	10	19.2
AUG	91	78	69	10.6	92	68	14	14.7
SEP	97	79	67	7.6	92	68	16	18.6
OCT	97	79	64	8.2	95	66	10	18.7
NOV	90	79	66	9.5	94	66	9	14.7
DEC	90	78	69	8.5	90	66	6	12.9

Figure 5-90. Thunderstorms, Precipitation, and Temperature: Wauna, Guyana.



MARIPASOULA FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	MAX DAY PRECIP
JAN	93	79	62	9.1	87	71	3	4.5
FEB	94	79	64	8.2	87	71	5	3.8
MAR	93	79	64	10.4	88	71	9	4.3
APR	93	80	66	12.3	88	71	7	3.9
MAY	95	80	65	15.1	88	72	11	4.5
JUN	94	79	67	12	89	71	10	3.5
JUL	94	79	65	8.4	88	71	9	2.9
AUG	96	80	67	6.1	89	71	9	2.7
SEP	97	80	64	3.4	91	70	6	3.3
OCT	98	81	62	2.9	92	70	6	3.4
NOV	98	81	64	4.2	91	71	6	2.8
DEC	97	80	65	6.4	88	71	7	5.6

Figure 5-91. Thunderstorms, Precipitation, and Temperature: Maripasoula, Fr Guiana.

ST LAURENT FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	MAX DAY PRECIP
JAN	91	78	64	9.6	84	73	3.9
FEB	92	78	66	7.6	85	72	5.6
MAR	91	79	67	8.1	85	72	5.1
APR	92	79	67	10.4	86	72	4
MAY	93	79	67	15	86	73	6.2
JUN	93	79	68	12.7	86	72	4.4
JUL	94	80	69	9.9	87	72	3.5
AUG	95	81	69	6.8	89	72	3.9
SEP	96	80	68	4.2	90	72	3.1
OCT	97	81	68	3.8	90	72	3.5
NOV	97	81	68	6.2	89	72	3.3
DEC	93	79	67	9.3	86	72	3.7

ST GEORGES FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	MAX DAY PRECIP
JAN	90	78	62	17.2	84	71	4.6
FEB	91	77	63	14.2	84	71	4.1
MAR	90	78	64	15.8	84	71	4.9
APR	91	78	64	18.1	85	71	6.3
MAY	91	78	65	21	86	72	6.8
JUN	92	78	66	14.5	86	71	4.5
JUL	97	78	65	7.9	87	70	3.6
AUG	95	79	63	4.5	88	69	2.1
SEP	96	80	64	2.3	90	68	2.4
OCT	96	80	65	2.9	91	69	2.3
NOV	96	79	63	5.2	89	70	6.4
DEC	94	78	63	13.2	86	71	4.1

Figure 5-92. Precipitation and Temperature: Five French Guiana Stations.

KOUROU FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	MAX DAY PRECIP
JAN	[illegible]	79	67	12.8	5.6
FEB	87	79	[illegible]	9.1	4.7
MAR	87	78	67	11.8	7.7
APR	87	[illegible]	67	14	8.5
MAY	[illegible]	79	[illegible]	21	9.3
JUN	[illegible]	78	68	14.7	5
JUL	[illegible]	78	[illegible]	7.3	3.6
AUG	[illegible]	79	67	3.4	2.8
SEP	93	79	66	1.8	2.4
OCT	92	80	67	2.7	2.8
NOV	91	80	66	5	4.7
DEC	89	79	68	12.5	4.8

SAUL FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	MAX DAY PRECIP
JAN	95	78	62	9.9	3.2
FEB	96	78	57	8.5	2.5
MAR	95	78	57	10.4	3.3
APR	94	79	62	11.5	4.4
MAY	95	79	62	13.8	3.8
JUN	94	79	62	10	5.4
JUL	93	79	60	7.1	2.9
AUG	96	79	61	5.2	5.7
SEP	97	79	60	2.4	1.9
OCT	96	80	59	2.9	3.7
NOV	97	80	61	4.7	3.2
DEC	95	78	60	7.9	9

CAMOPI FR GUIANA

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	MAX DAY PRECIP
JAN	93	78	65	12.8	8
FEB	93	78	64	11.6	18.7
MAR	95	78	64	11.8	3.5
APR	96	79	63	12.4	4.1
MAY	94	78	61	14.9	3.7
JUN	95	79	65	10	3.5
JUL	94	79	66	6.9	3
AUG	96	80	64	4.5	2.8
SEP	97	80	65	2.4	2.4
OCT	99	81	64	1.8	1.7
NOV	97	80	64	3.9	2.8
DEC	95	79	65	7.8	2.8

Figure 5-92, Cont'd. Precipitation and Temperature: Five French Guiana Stations.

WINDS. The northeasterly trades average 10 to 15 knots along the coast and inland for 30 to 50 miles (50 to 80 km). Further inland, they decrease to 5-10 knots. Nighttime winds die, becoming nearly calm except along the immediate coast. Strong winds--above 50 knots--are associated with the rare severe thunderstorm.

THUNDERSTORMS. Thunderstorms are found along the southern edge and core of the Monsoon Trough, and with trade wind/polar surges. Total wet season thunderstorm days average near 30. Favored thunderstorm locations are in the area from 10 to 80 miles (16 to 120 km) inland and over the Guyana Highlands, which see. No hail has been reported, but isolated reports of forest "blowdowns" in the interior indicate that the "downburst" phenomenon has occurred there.

PRECIPITATION. Wet season rainfall averages 67 inches (1,700 mm) in western Guyana, and 95 inches (2,400 mm) in eastern French Guiana. Almost 75% of this falls from December to January and from June to July. See Figure 5-93.

TEMPERATURE. Highs are from 84 to 86°F (29 to 31°C); lows, from 72 to 77°F (22 to 24°C).

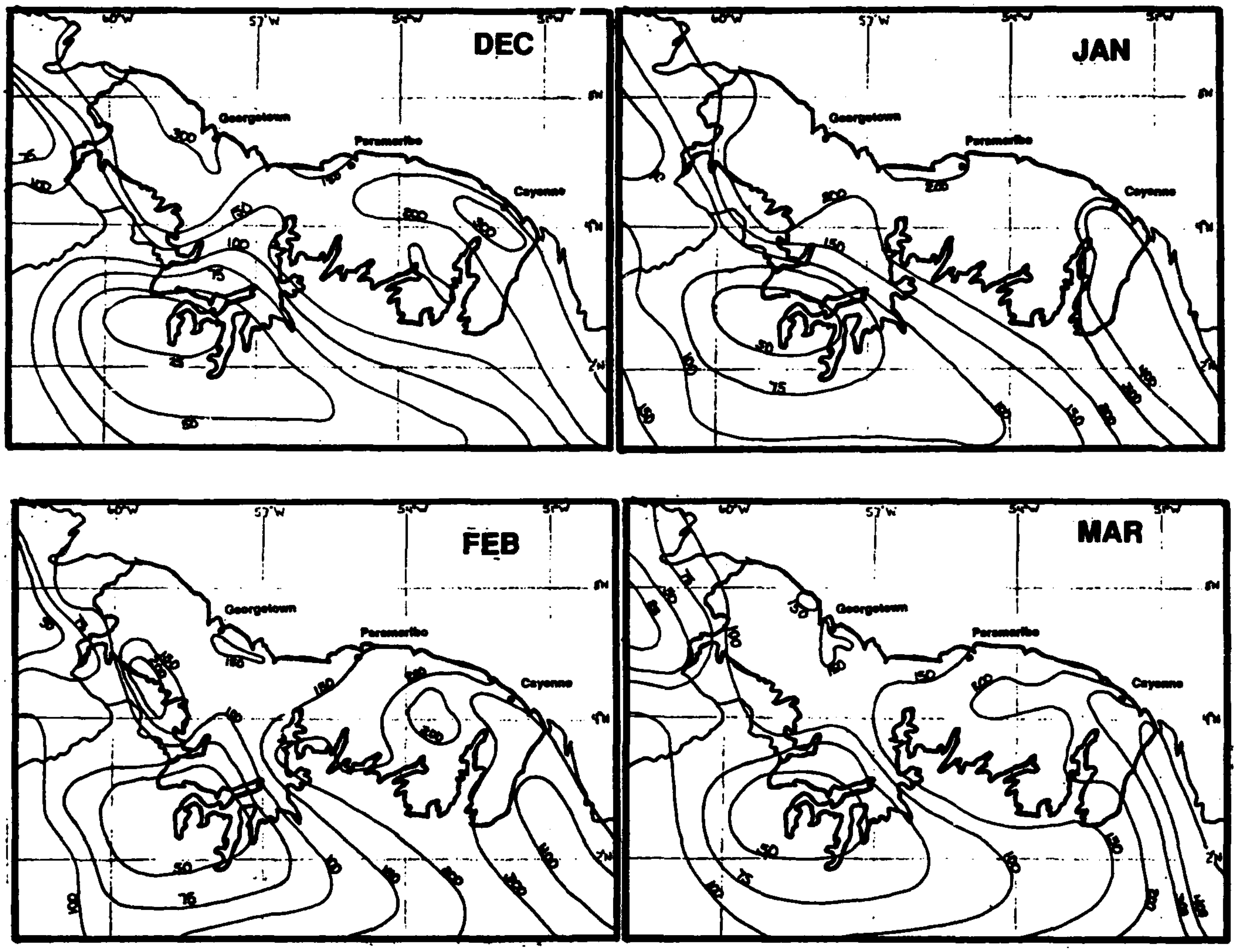


Figure 5-93. Mean Monthly Precipitation: December-March.

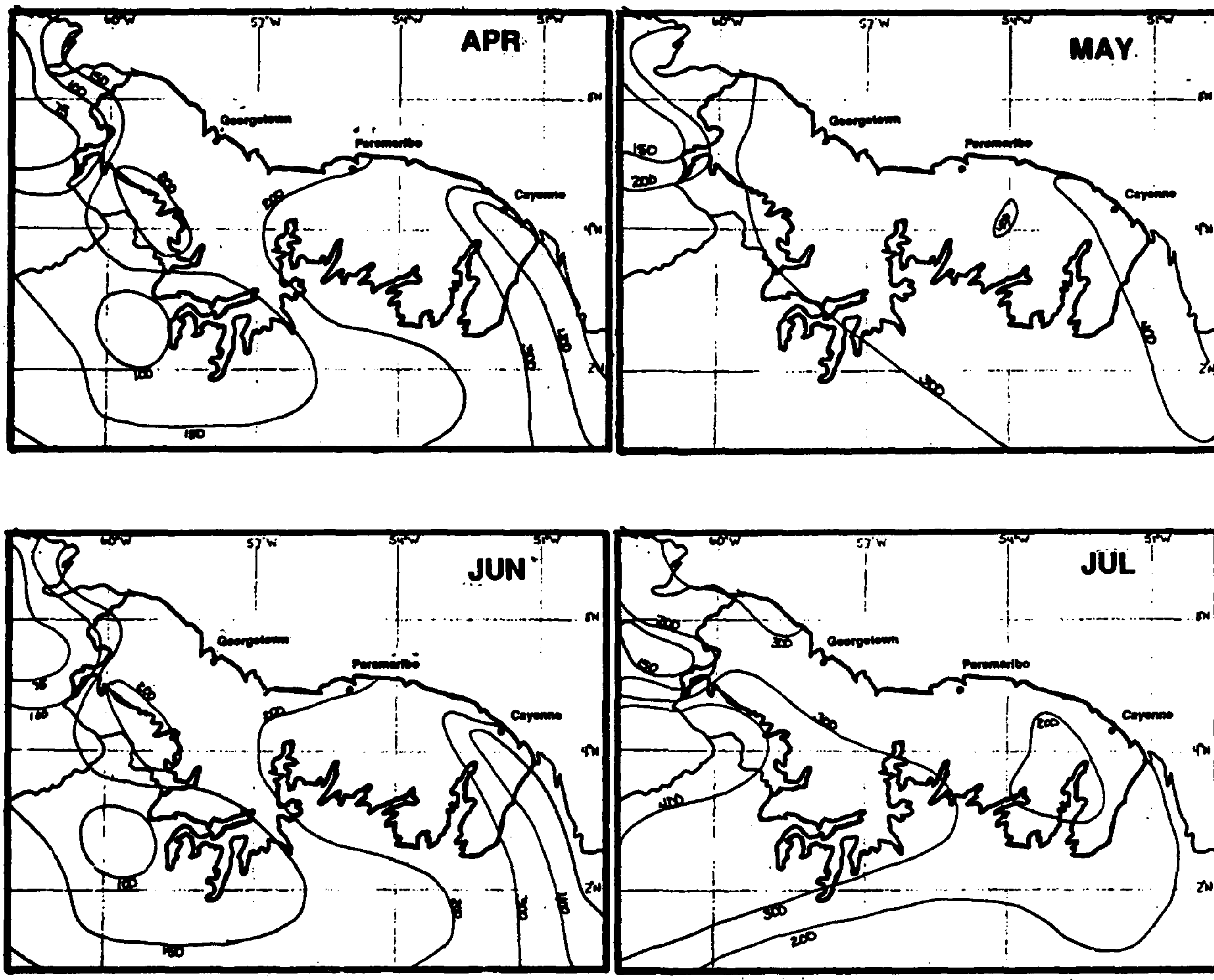


Figure 5-93, Cont'd. Mean Monthly Precipitation: April-July.

GENERAL WEATHER. Southeasterly trades from the South Atlantic High move onshore south of the Monsoon Trough. Flowing northwestward toward the Monsoon Trough, they lose the well developed subsidence inversion found over the South Atlantic Ocean. This trade wind air is, however, relatively stable compared to that in the northeast trades; "rain" regimes are not characteristic of these winds, but continental heating generates isolated showers and thundershowers--some severe.

SKY COVER. When the Monsoon Trough passes over the Guyanas, the immediate coast to 10 miles (16 km) inland sees multilayered overcast altocumulus/ altostratus with bases at 3,300 feet (1,000 meters) and tops to 14-16,000 feet (4,200 to 4,900 meters). There is also 5-7/10 low cloud cover, with bases at 300-500 feet (90-150 meters) in layers up to 2,500 feet (800 meters). Visibilities average 0.6 to 1.25 mile (1 to 2 km) in rain and rainshowers. Thunderstorms--some strong--occur over the entire region. The worst weather (and most thunderstorms) occurs in the afternoon. These conditions occur as "rainy spells" separated by 1- to 3-day periods of weather similar to that of the southeast trades, which see.

As the transition season ends, conditions improve to multilayered, overcast altocumulus/altostratus with bases at 10,000 feet (3,000 meters) and tops at 14,000 feet (4,200 meters) overlying banks of stratus and stratocumulus with bases at 1,000 feet (300 meters) and tops at 5,000 feet (1,500 meters). Visibilities range from 3 to 7 miles (6 to 10 km) in light to moderate intermittent rain. Thunderstorms occur along the southern edge of the Monsoon Trough. Fog forms near sunrise, but dissipates near 0700 LST.

In the southeast trades immediately behind the Monsoon Trough, mornings are clear. By afternoon, heavy towering cumulus and cumulonimbus have formed in the interior. Isolated towering cumulus or cumulonimbus forms along the coast in late evening; bases average 2,500 feet (800 meters) and tops reach 40,000 to 50,000 feet (12.2 to 15.2 km). Visibility is good, but can drop to less than 0.5 mile (800 meters) in heavy showers. Thunderstorms dissipate rapidly after sunset, but heavy coastal cumulus may remain until after sunrise.

Conditions typical of the height of the rainy season occur with trade wind surges on the north side of the Trough. Ceilings lower to 300 to 500 feet (90 to 150 meters), with multilayered altocumulus/altostratus and embedded heavy towering cumulus and cumulonimbus. Visibilities range from 2-4 miles (3-6 km) in rain to 0.5 mile (800 meters) or less in showers and thundershowers. Such conditions normally last for only 12 to 18 hours.

WINDS. The northeasterly trades average 10 to 15 knots. Southeasterly trades are recognizable only on the coasts, with speeds at 5 to 10 knots. In the interior, winds are light and variable. Strong winds--above 50 knots--only occur with thunderstorms.

THUNDERSTORMS. Thunderstorms are found along the southern edge and core of the Monsoon Trough, and with trade wind surges north of the Trough. No hail has been reported, but strong winds do occur with some of the more severe thunderstorms associated with the southeasterly trades.

PRECIPITATION. Transition rainfall, as shown in Figure 5-94, ranges from near 8 inches (200 mm) in western Guyana to near 12 inches (300 mm) near the Brazilian border.

TEMPERATURE. Highs range from 84 to 86°F (29 to 31°C) in the northeast trades to 88 to 92°F (31 to 33°C) in the southeast trades. Lows vary from 72 to 77°F (22 to 24°C) in the northeast trades to 66 to 70°F (19 to 21°C) south of the Monsoon Trough.

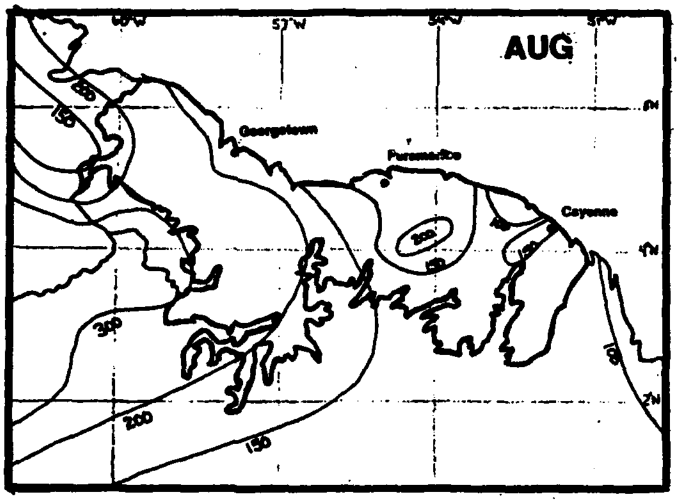


Figure 5-94. Mean Precipitation: August.

GENERAL WEATHER. Air flowing over the Guyanas is now relatively dry and stable; the trade wind inversion is at its strongest. Precipitation is typical of that found in a tropical "showers" regime. Only a very rare southern hemisphere cold frontal penetration changes these conditions.

SKY COVER. Mornings are clear. By afternoon, heavy towering cumulus and cumulonimbus have formed in the interior; isolated towering cumulus or cumulonimbus forms along the coast in late evening. Bases average 2,500 feet (800 meters); tops reach 40,000 to 50,000 feet (12.2 to 15.2 km). Visibility is good, but may drop to less than 0.5 mile (800 meters) in the heaviest showers. Thunderstorms dissipate rapidly after sunset, but the heavier coastal cumulus does not dissipate until after sunrise.

Lines of well developed thunderstorms move northeastward along and ahead of the rare southern hemisphere cold front. Ceilings lower to 300 to 500 feet (90 to 150 meters), with multilayered altocumulus/ altostratus and embedded heavy towering cumulus and cumulonimbus. Visibilities range from 2-4 miles (3-6 km) in rain down to 0.5 mile (800 meters) or less in heavy showers. These conditions seldom last beyond 12 to 18 hours.

WINDS. The southeasterly trades average 5 to 10 knots along the coast, but are light and variable in the interior. Wind speeds exceed 30 knots only in thunderstorms.

THUNDERSTORMS. Isolated afternoon and evening thunderstorms--some with winds above 50 knots--may occur over the interior during the afternoon. Squall lines ahead of the infrequent southern hemisphere cold front occur at any time, day or night, but the strongest are in late afternoon.

PRECIPITATION. Dry season rainfall ranges from near 31 inches (800 mm) in western Guyana to near 47 inches (1,200 mm) in eastern French Guiana. See Figure 5-95.

TEMPERATURE. Highs range from 88 to 92°F (31 to 33°C); lows from 66 to 70°F (19 to 21°C).

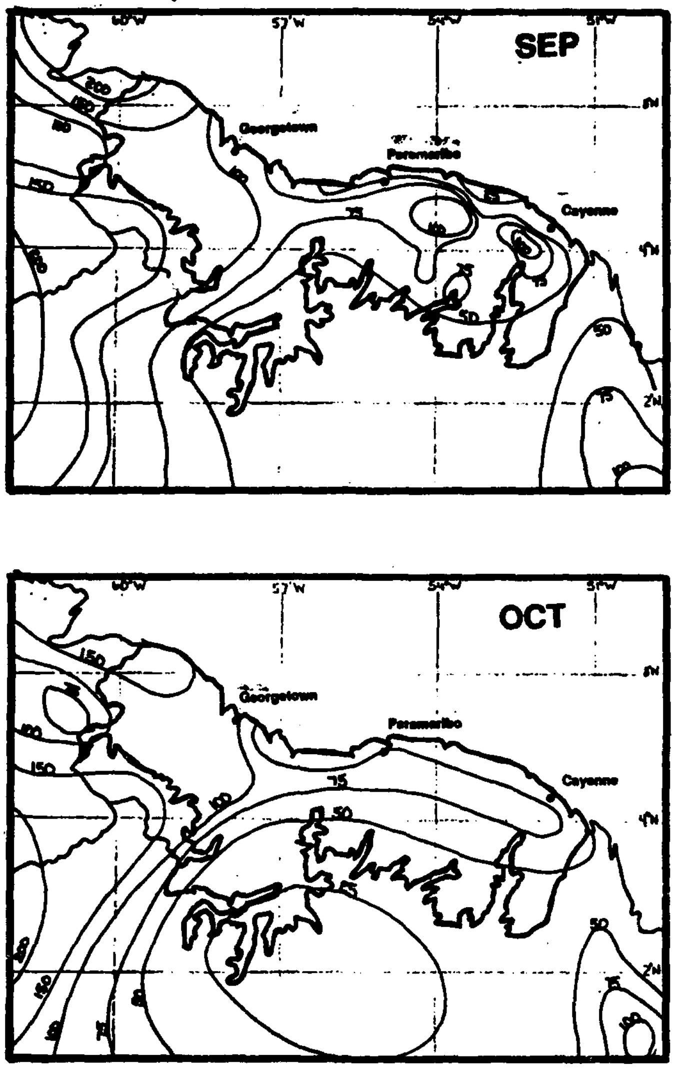


Figure 5-95. Mean Monthly Precipitation: September & October.

GENERAL WEATHER. Although most of the Guyana Coastal Plains have a rapid dry-to-wet transition in November and early December, the Brazilian frontier area of French Guiana sees the transition a bit later--in December.

SKY COVER. As the transition starts, conditions deteriorate to multilayered overcast altocumulus/altostratus with bases at 10,000 feet (3,000 meters) and tops to 14,000 feet (4,200 meters) above banks of stratus and stratocumulus with bases at 1,000 feet (300 meters) and tops at 5,000 feet (1,500 meters). Visibilities range from 3 to 7 miles (6 to 10 km) in light to moderate intermittent rain. Thunderstorms occur along the southern edge of the Monsoon Trough. Fog reduces visibilities to less than 0.5 mile (800 meters) near sunrise, but dissipates near 0700 LST.

Once the Monsoon Trough has reached the Guyana coastline, the immediate coast to 10 miles (16 km) inland sees multilayered overcast altocumulus/altostratus with bases at 3,300 feet (1,000 meters) and tops to 14-16,000 feet (4,200 to 4,900 meters). Low cloud cover is 5-7/10, with bases from 300 to 500 feet (90 to 150 meters) in layers up to 2,500 feet (800 meters). Visibilities average 0.6 to 1.25 miles (1 to 2 km) in rain and rainshowers. Thunderstorms--some strong--occur over the entire region. The worst weather (and most thunderstorms) occurs in the afternoon. These conditions occur as "rainy spells" separated by 1- to 3-day periods of weather similar to that of the southeast trades, which see.

Conditions that typify the height of the wet season occur with trade wind surges on the north side of the Monsoon Trough. Ceilings lower to 300 to 500 feet (90 to 150 meters) with multilayered altocumulus/altostratus and embedded heavy towering cumulus and cumulonimbus. Visibilities range from 2-4 miles (3-6 km) in rain, dropping to 0.5 mile (800 meters) or less in showers and thundershowers. Such conditions seldom last beyond 12 to 18 hours.

WINDS. The northeast trades average 10 to 15 knots; the southeast trades average 5 to 10 knots along the coast but are light and variable in the interior. Strong winds--above 50 knots--only occur with thunderstorms.

THUNDERSTORMS are found along the southern edge and core of the Monsoon Trough, and with trade wind surges north of the Trough. No hail has been reported, but winds over 50 knots occur with some of the most severe thunderstorms associated with the southeasterly trades.

PRECIPITATION. Transition rainfall ranges from near 8 inches (200 mm) in western Guyana to near 12 inches (300 mm) in eastern French Guiana. See Figure 5-96.

TEMPERATURE. Highs range from 84 to 86°F (29 to 31°C) in the northeast trades to 88 to 92°F (31 to 33°C) in the southeast trades. Lows are from 72 to 77°F (22 to 24°C) in the northeast trades, and from 66 to 70°F (19 to 21°C) south of the Monsoon Trough.

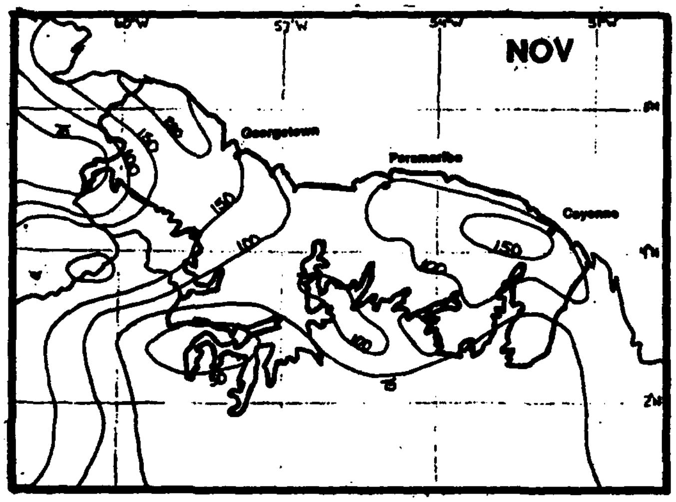


Figure 5-96. Mean Precipitation: November.

5.8 THE GUYANA HIGHLANDS

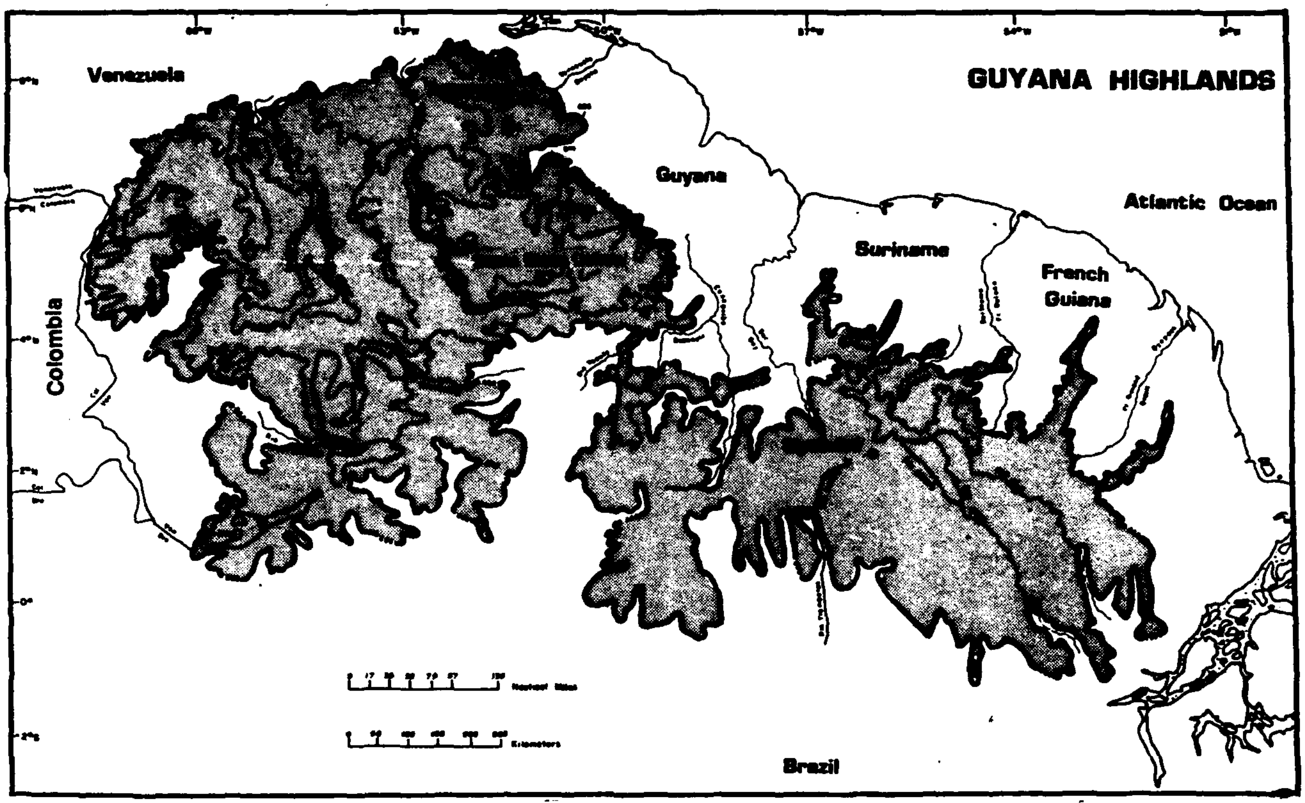


Figure 5-97. The Guyana Highlands. This region is formed by a large mountain and upland block with elevations above 1,640 feet (500 meters). It is bounded by the Orinoco River on the west and northwest, the coastal plains on the northeast and east, and the northern Amazon basin on the south. The primary range is the Sierra Pacaraima along the southeastern Venezuela-Brazil border. Highest known elevation is 9,219 feet (2,772 meters) in extreme southeast Venezuela near the intersection of the Venezuela-Guyana-Brazil borders. Most of the area is tropical rain forest. Northern slopes in Venezuela are tropical savanna.

GUYANA HIGHLANDS GEOGRAPHY

BOUNDARIES. The Guyana Highlands are bounded:

On the south by a line westward from the Amazon Delta on the Brazilian Atlantic coast along the 1,640-foot (500-meter) contour line into northern Amazonas State, Brazil. North from this point, then northeast to the 1,640-foot (500-meter) contour line on the northern side of the Venezuela-Brazil frontier at about 2° N, 66° W.

On the west, starting from a point at 2° N, 66° W, east and then north along the 656-foot (200-meter) contour line along the east side of the Orinoco drainage from the ridge separating the Orinoco and Amazon river drainages at 66° W to a point abeam the intersection of the Meta River with the Orinoco River.

On the north, along the 656-foot (200-meter) contour line on the east and south banks of the Orinoco River from abeam the intersection of the Meta River with the Orinoco River to the coastal plains on the south side of the Orinoco Delta.

On the east, southward from the 656-foot (200-meter) contour line above the coastal plains facing the Orinoco Delta rising slowly to the 1,640-foot (500-meter) contour line above the coastal plains near the northwest side of the Amazon Delta.

TERRAIN. According to 1982 Defense Mapping Agency aeronautical charts and information acquired in discussions with Venezuelan National Meteorological Service staff in November 1983, terrain elevations in this region are not well defined and should be suspect. Adequate aerial mapping has not been conducted here; even the most recent aeronautical navigation charts indicate "Relief Data Incomplete." In several areas, charts carry notations such as "Abrupt cliffs reported in this area--hazardous flying under 13,000 feet" and "Abrupt cliff reported 7,500 (feet)."

The "Guyana Highlands" actually comprise a cluster of three mountainous regions that stretch from the Brazil-French Guiana border westward through southern Venezuela. All three of these regions are composed of extensive ranges and deep valleys. Mountains are of two types: steep-sided peaks and large flat "table" mountains similar to the mesas of the American southwest, but much larger.

The eastern region contains the Tumuc-Humuc mountains and covers the southern portions of French Guyana and Suriname as well as most of Brazil north of the Amazon River. The eastern area ends at approximately 57° W (the Suriname-Guyana border and, in Brazil, the Trombetes-Anamu Rivers). The highest mountains are along the Brazil-French Guiana border near 54° W along the Brazil-Suriname border between 55 and 56° W, and north-northwestward along the Wilhelminia Range from 56° W west to 4° N, 57° W. The highest known elevation is at Juliana Top (4,517 feet--1,377 meters). Average maximum elevations are between 1,640 and 3,280 feet (500 and 1,000 meters). Elevations in the rest of the area average between 656 feet (200 meters) and 1,640 feet (500 meters), with isolated peaks in southern French Guiana that are known to reach 2,805 feet (855 meters). Despite relatively low elevations, terrain gradients are steep, especially on the Brazilian side; aeronautical charts show numerous waterfalls in all major rivers that drain these mountains.

The central region extends northwestward from about 57° W along the Brazil-Guyana border to its intersection with the Tacutu River at about 3° 35' N, 59° 55' W. Primarily rugged but low (elevations are 656-1,640 feet--200-500 meters), the central highlands extend for 40 to 60 miles (64 to 96 km) on either side of the border. The area in a band 20 miles (32 km) wide on either side of the frontier is rugged, with sharp terrain gradients. Maximum elevations are in a small sector along the frontier from 58° W to 59° 20' W. Heights here average 1,700-2,500 feet (519-762 meters); one peak reaches 3,310 feet (1,010 meters).

The western region of the Guyana Highlands is separated from the central and eastern regions by the Brancho-Tacutu river system in Brazil and, after crossing a low divide, the Essequibo-Rupununi system in Guyana. The former flows into the Amazon; the latter into the Atlantic Ocean. From here, the western area (a combination of mountains, river basins, and mesas) occupies all of Venezuela north and west to the Orinoco River. In Brazil, it covers the area north of the northern Amazon basin above the 1,640-foot (500-meter) contour line westward to the Negro River drainage basin at about 66° 30' W. The western Guyana Highlands can be further subdivided into three smaller areas by three major river systems, all rising in the main range along the Brazil-Venezuela border.

In Venezuela, the Caroni-Paragua river system rises near the Venezuela-Brazil border between 61 and 63° W. The Grand Savannah (la Gran Sabana) lies east and southeast of this river system to merge with the Kuringike Mountains of southwestern Guyana to form one large, rugged mountain area. The highest known peak in Venezuela--Mt Roraima, elevation 9,200 feet (2,772 meters)--lies at the junction of Venezuela, Brazil, and Guyana. Average elevations in this complex are from 3,000 to 6,000 feet (915 to 1,830 meters) with isolated peaks to 8,900 feet (2,715 meters). Much of the Grand Savannah consists of very large flat-topped "table mountains," often with elevations above 8,500 feet (2,590 meters). Sides of these mesas are extremely steep, often falling several thousand feet before reaching general terrain heights. In most cases, terrain gradients (except for mesa tops) are extremely steep.

Another separate mountain area in Venezuela lies between the Caroni-Paragua river system and the Caura-Ereveto system, which rises near the Venezuelan-Brazil frontier between 63 and 64° W. Like the Caroni-Paragua, the Caura-Ereveto flows northward into the Orinoco. Between the two systems lie the Zamuro Mountains (Sierra del Zamuro), a range oriented north-northwest to south-southeast and extending from the Venezuela-Brazil frontier to the Orinoco. Known peak elevations are 6,900 feet (2,100 meters) on a large mesa near 5° 50' N, 63° 45' W. Average elevations are from 2,000 to 5,000 feet (610 meters).

Still in Venezuela, a third area of the Western Guyana Highlands lies mostly between the Orinoco and the Caura Rivers, including the "spine" mountain range lying along the Venezuela-Brazil frontier and surrounding the headwaters of the Orinoco west of 64° W. In Brazil, the area extends over the "spine" mountain range southwest of the Uraricoera River along the frontier westward to the Negro River drainage system, then southward to the 1,640-foot (500-meter) contour on the north side of the Amazon River system. (The Orinoco headwaters region below 656 feet/200 meters is not included here, but is discussed in the Orinoco River section of this study.) Highest known elevations are about 10,300 feet (3,140 meters) along the Venezuela-Brazil frontier near 66° W. Many peaks in the 8,000- to 8,500-foot (2,440- to 2,590-meter) range have been reported throughout this area.

VEGETATION. Vegetation in the Guyana Highlands is of three types: tropical rain forest (or minor modifications thereof), deciduous forest, and savannah. Because of the extremely rugged terrain and the resultant small scale "rainshadow" effects, isolated pockets of one vegetation type may exist within general areas of another type. Compounding the identification problem is the fact that the area is poorly mapped.

Tropical rain forest with anywhere from a five- to three-tier structure covers the entire region up to about 5° N. Elevations above 3,000-4,000 feet (915-1,220 meters) normally support the smaller (three-tier) version. Tropical rain forest is also found in the immediate vicinity of major rivers north of 5° N.

Because of decreasing precipitation, elevations above 3,000-4,000 feet (915-1,220 meters) north of 5° N are normally covered by deciduous broadleafed forest, which is also normally found on the top of high (6,500-8,500 feet/1,980-2,590 meters) flat-topped, or "table" mountains.

The northern, and lower, end of the region sees a gradual transition to tropical savannah that extends northward to the Orinoco River Basin. Mostly covered by 1- to 5-foot (0.3- to 1.5-meter) coarse grass, this area also has isolated trees which, at lower elevations, are palms.

NOTES ON GUYANA HIGHLANDS WEATHER AND CLIMATE

Because of its elevation, extremely rugged relief, and proximity to the Monsoon Trough, seasons in the Guyana Highlands have much more in common with those of Venezuela than of either Brazil or the Guyanas. Basically, the regime here is a tropical northern hemisphere precipitation distribution. The wet season is in the "summer," and the dry season is in the "winter."

The Guyana "Highlands" are perhaps better described as "mountains." Cloud cover, precipitation, wind, thunderstorms, and fog here vary dramatically from ridge to valley. Complex mountain valley wind patterns further complicate conditions. All cloud heights are given above MSL. There has been no attempt to provide ceiling heights, which must be inferred from local terrain elevations. Summarized data is available only from mountain valley stations.

Even though there are few reporting stations in the Guyana Highlands, the information presented in the following discussions of weather and climate is believed to be as accurate as possible; every available information source, both in the United States and in South America, plus extensive satellite imagery, has been used. Readers should understand, however, that these descriptions must necessarily be considered provisional.

GENERAL WEATHER. The Monsoon Trough's movement northward ends the dry season. Increasing convergence in the northeast trades preceding the Monsoon Trough overrides the effects of rugged terrain relief. Aiding this process is the steadily increasing sun angle. Trough movement is known to lag the solar cycle by 2-3 months. Satellite imagery indicates the early June formation of a new "Monsoon Trough" in the Orinoco Basin (see Figure 5-98) in response to the northward movement of the oceanic Monsoon Trough. The old trough apparently does not cross the Guyana Highlands intact. Figure 5-99 gives an example of well-defined convergence along the Monsoon Trough between the two trade wind currents. In the Guyana Highlands, unlike the Amazon and the Guyana Coastal Plains, the southeast trades provide the "rains" regime.

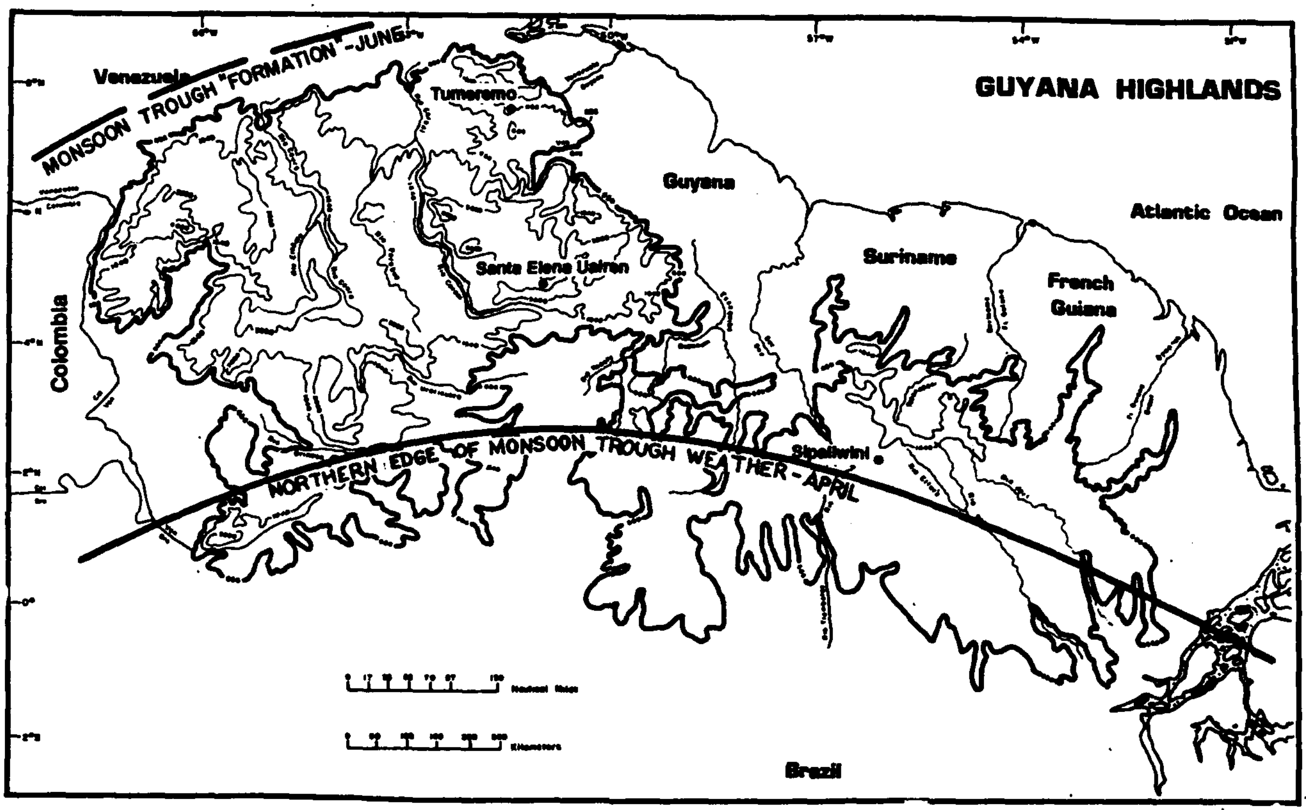


Figure 5-98. Low-Level Monsoon Trough Movement.

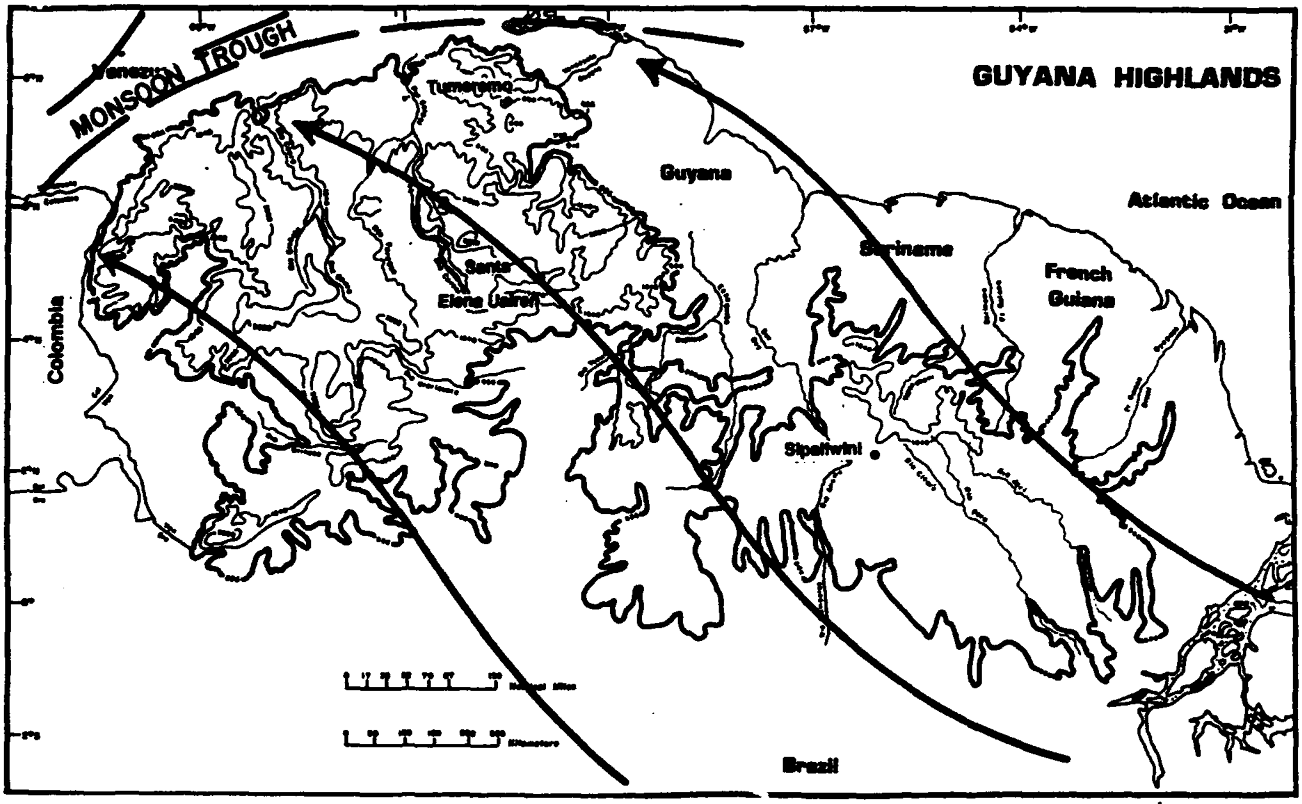


Figure 5-99. Convergence Along the Monsoon Trough.

SKY COVER. In the immediate area of the advancing Monsoon Trough, sunrise finds widespread overcast valley stratus decks up to 2,500 feet (765 meters). Fog may or may not occur underneath these decks depending on whether winds are upslope or downslope, and whether or not precipitation is occurring. Deep valleys are more likely to have dense fog. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus, altostratus, or cirrostratus. Isolated heavy cumulus may also be found along southeastern-facing ridges. Tops range from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 1000 LST, the stratus has dissipated and heavy cumulus begins to form along mountain ridges and over flat-topped mesas above 3,500 feet (1,070 meters). By 1200 LST, most ridges and mesa tops see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, numerous thunderstorms--some strong--occur over the entire region, but dissipate after sunset. Showers occur by late evening. Stratus decks form in valleys after midnight.

In the retreating northeast trade winds, patchy low stratus decks form near dawn in low-lying valleys, dissipating by 0900 LST. Isolated cumulus forms over ridge lines by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus over the higher mountains or mesas builds to 15,000 feet (4.6 km) wherever local heating and or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Worse conditions--typical of the wet season--occur with mesoscale convective complexes in the Monsoon Trough.

Figures 5-100, 5-101, and 5-102 give summarized ceiling and visibility frequencies from three widely separated mountain valley stations: Tumeremo, Venezuela (in the northern Highlands near the Orinoco), Santa Elena Uairen, Venezuela (in the central Highlands, not far from the highest known mountain in the area and the only station with even fragmentary night observational records), and Sipaliwini, Suriname (in the eastern Highlands). Because of the terrain considerations noted earlier, treat these data with caution. Do not use them to infer conditions in other parts of the Guyana Highlands.

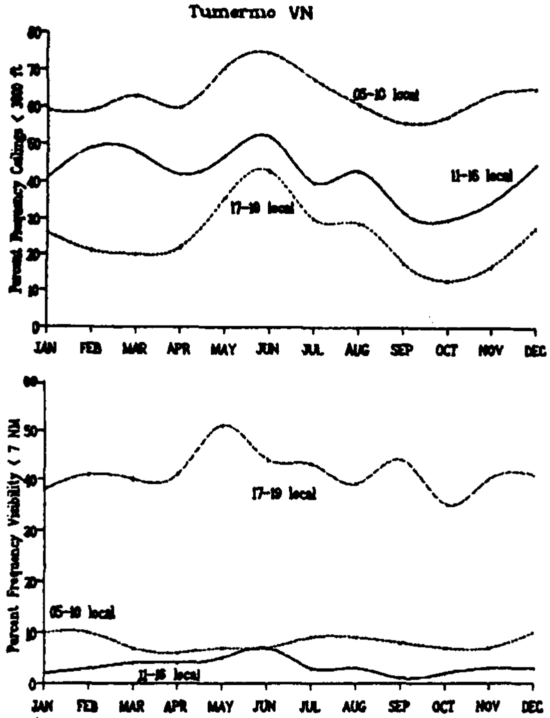


Figure 5-100. Percent Frequency Ceiling and Visibility <3,000/7: Tumeremo, Venezuela.

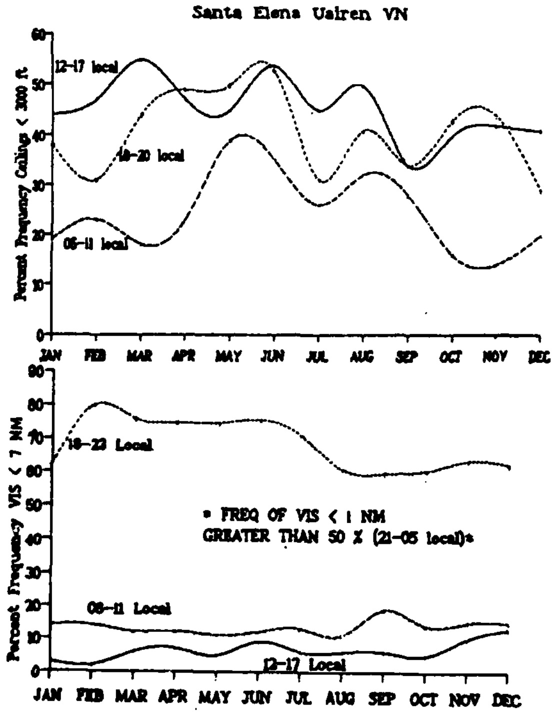


Figure 5-101. Percent Frequency Ceiling and Visibility <3,000/7: Santa Elena Uairen, Venezuela.

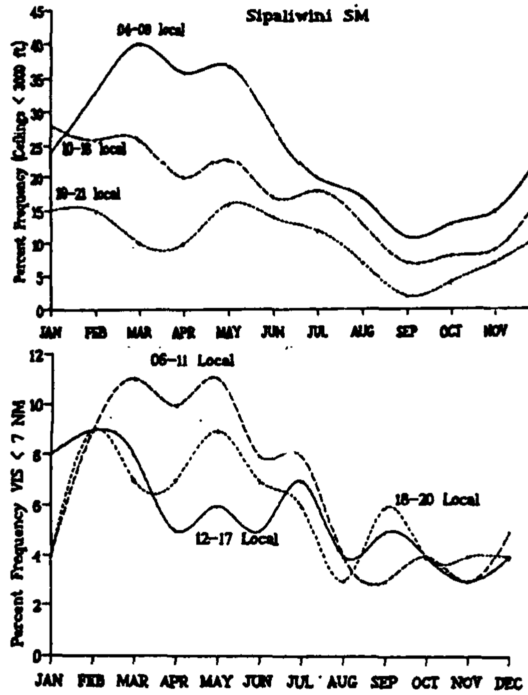


Figure 5-102. Percent Frequency Ceiling and Visibility <3,000/7: Sipaliwini, Suriname.

WINDS. As the southeast trades set in, gradient flow changes from east-northeasterly at 10 to 15 knots to east-southeasterly at 10 to 15 knots. Surface flow varies with terrain.

THUNDERSTORMS are found along the windward sides and crests of mountain ridges in those areas affected by the Monsoon Trough. Over the eastern Highlands, thunderstorms are enhanced in mesoscale convective complexes.

PRECIPITATION. Rainfall ranges from 7.9 inches (200 mm) in southwestern French Guiana to 3.9 inches (100 mm) in the northwestern Highlands. Figure 5-103 gives mean March precipitation for the entire area.

TEMPERATURE. Temperatures vary with altitude. At lower elevations, highs are 84 to 88° F (29 to 32°C); lows from 72 to 77°F (22 to 24°C). In the highest mountains, highs are 50 to 60°F (10 to 15°C); lows are 39 to 45°F (4 to 7°C).

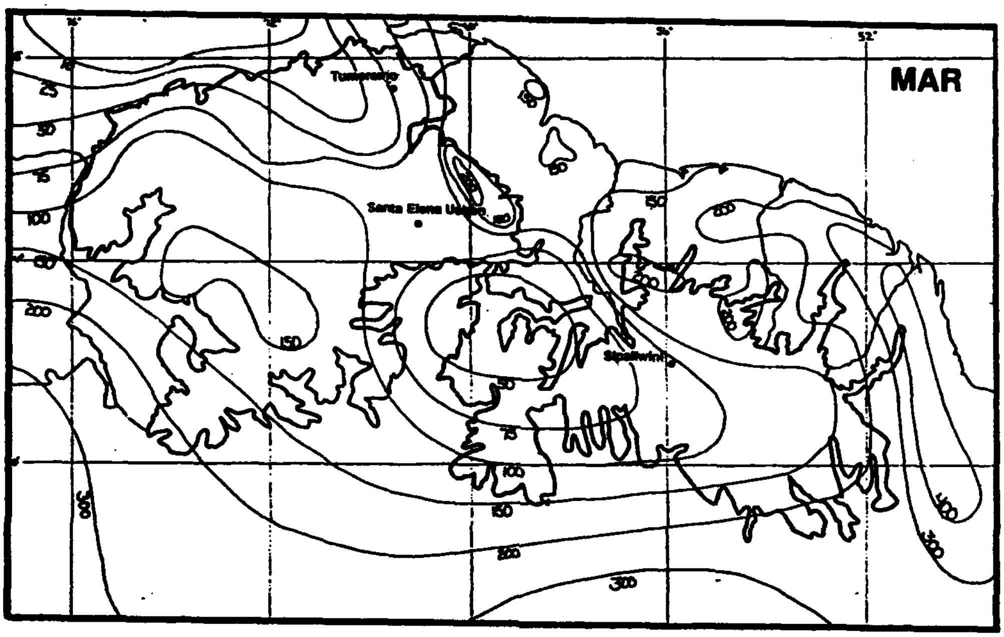


Figure 5-103. Mean Precipitation: March.

GENERAL WEATHER. Southeasterly trades from the South Atlantic High move over the Guyana Highlands throughout the wet season. In the Guyana Highlands, unlike the Amazon and the Guyana Coastal Plains, the southeast trades provide the "rains" regime. The combination of continental heating and constant water vapor influx from the Amazon Basin ensures that this air is conditionally unstable before it reaches the Highlands. The remnants of the original South Atlantic tradewind inversion are quickly overcome by large scale orographic lift that provides the trigger for heavy convection. Figure 5-104 shows mean upper-level wind direction at Santa Elena Uairen. Note the steady easterly 10,000-foot (3,050-meter) winds that are favorable for precipitation.

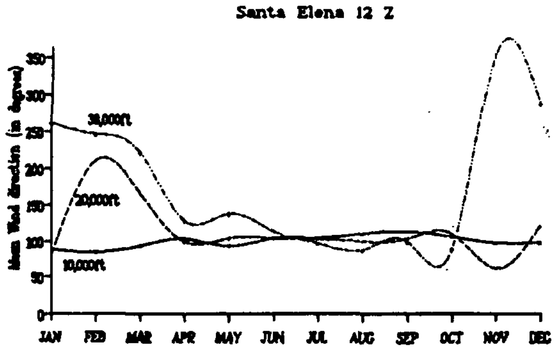


Figure 5-104. Upper-Level Winds: Santa Elena Uairen, Venezuela.

Southern hemisphere polar surges begin to reach the flanks of the southern Highland by late June and early July. An occasional surge penetrates to the Orinoco; an extremely strong, and very rare, surge may reach the Caribbean coast of Venezuela. The primary effects of such surges are to organize convection into lines and enhance orographic precipitation. Figure 5-105 (from Parmenter) shows continuity of a mid-July 1975 sub-Antarctic surge that reached the Caribbean.

Meyers (1964) reported that a surge similar to the one depicted in Figure 5-105 was responsible for torrential rains in the Guyana Highlands during 1957. Unfortunately, there is no data that gives us mean frequencies of surge occurrence here. But Brazilian and Venezuelan meteorologists have told the senior author that they believe three to five surges a year--all during the rainy season--reach at least to the southern edge of the Guyana Highlands.

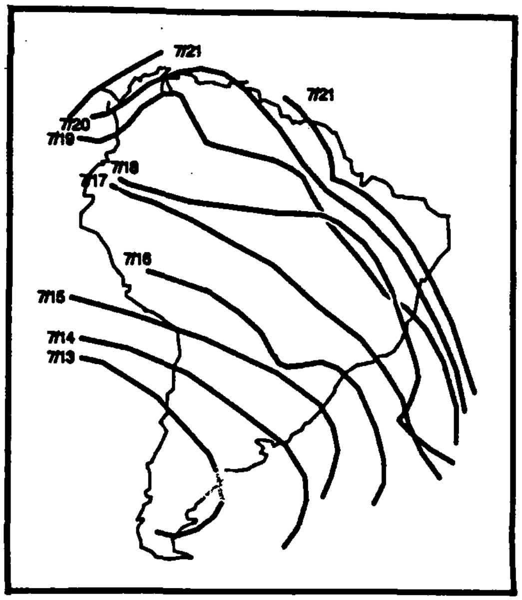


Figure 5-105. Sub-Antarctic Surge Continuity: 13-21 July 1975.

With polar surges or mesoscale convective complexes, convection increases; widespread heavy towering cumulus and cumulonimbus occur over the entire region. These events provide the heaviest precipitation events of the wet season. Fragmentary reports show maximum daily precipitation in excess of 6 inches (150 mm), but actual amounts may be much higher. Minimum occurrences are from 0300 to 0900 LST.

SKY COVER. In the absence of polar surges, dawn sees widespread overcast valley stratus decks up to 2,500 feet (765 meters). Fog may or may not occur under these decks depending on whether winds are upslope or downslope and whether or not precipitation is occurring. The deeper the valley, the stronger the likelihood fog will form. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus. Isolated heavy cumulus may be found along southeastern-facing ridges. Tops are variable, ranging from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 1000 LST, the stratus decks have dissipated; heavy cumulus begins to form along mountain ridges and over

flat-topped mesas above 3,500 feet (1,070 meters). By 1200 LST, most ridges and mesa tops see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, numerous thunderstorms --some strong--occur over the entire region, but dissipate after sunset. There are showers by late evening. Stratus decks form in valleys after midnight. Refer to Figures 5-100 through 5-102 for valley ceiling and visibility summaries.

WINDS. Gradient flow is east-southeasterly at 10 to 15 knots. Surface flow varies with terrain. Stronger winds occur with thunderstorms over higher ridges or mesas.

THUNDERSTORMS. Thunderstorms are found along the windward sides and crests of most ridges by late morning. Widespread thunderstorm activity is a result of polar surges or mesoscale convective complexes; most occur in the wet season. Severe thunderstorms have been reported over higher mountains.

PRECIPITATION. Wet season rainfall ranges from 55 inches (1,400 mm) in southwestern French Guiana to 71 inches (1,800 mm) in southern Venezuela. See Figure 5-104.

TEMPERATURE. Temperature varies with altitude. At lower elevations, highs are 84 to 86°F (29 to 31°C), lows from 72 to 77°F (22 to 24°C). In the highest mountains, highs are only 45-55°F (5-13°C), lows only 39-45°F (4-7°C).

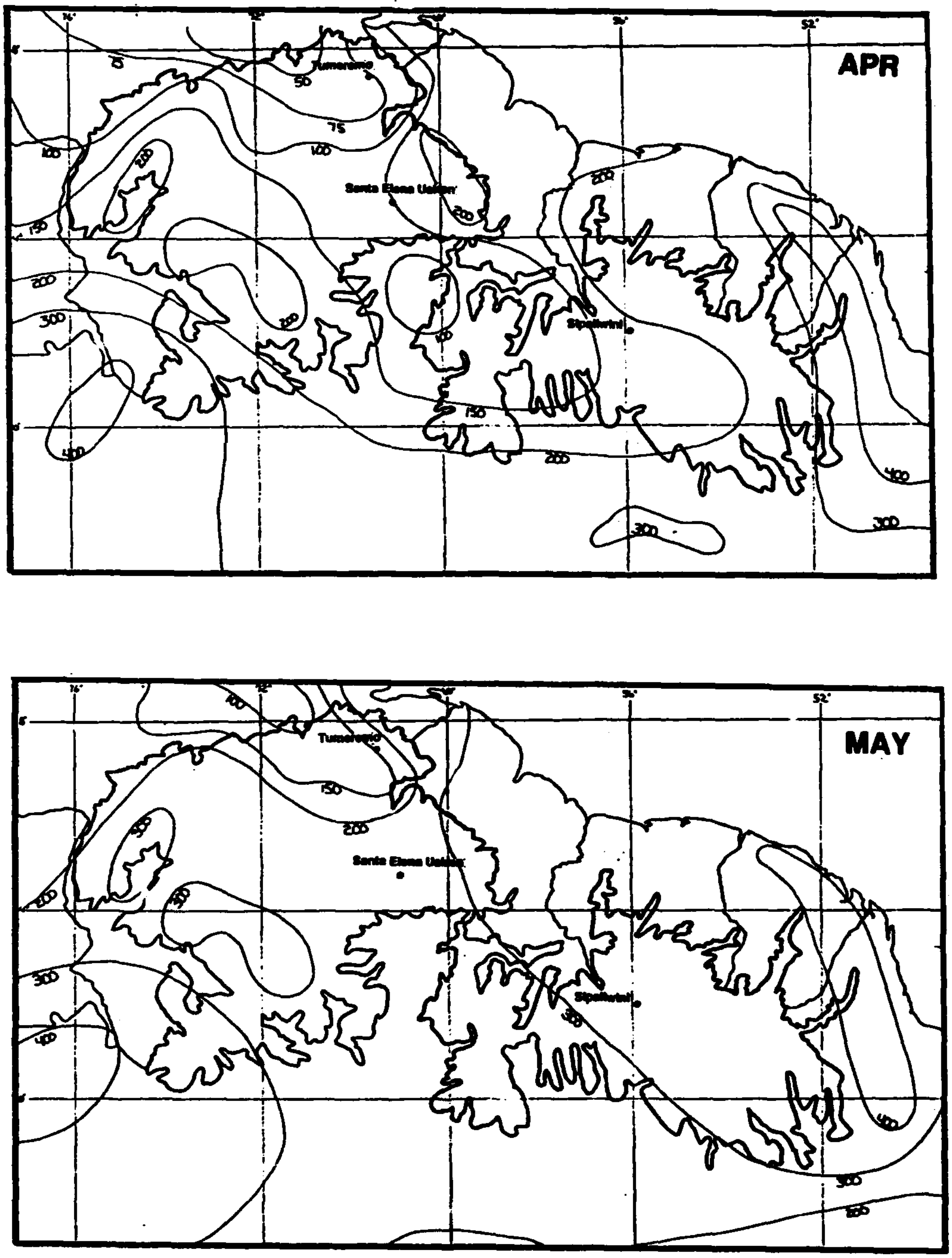
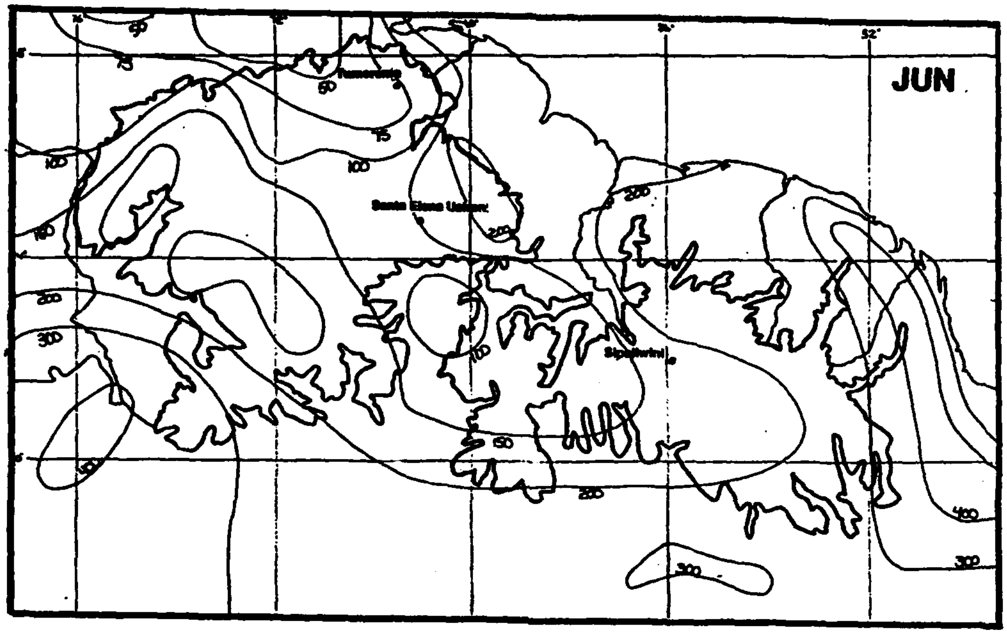


Figure 5-106. Mean Monthly Precipitation: April-May.



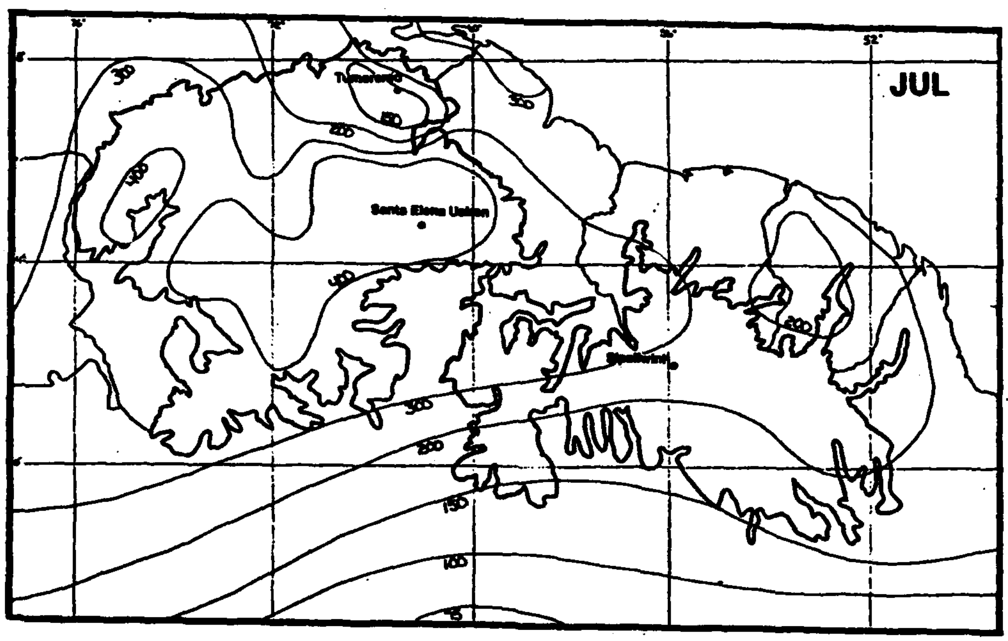


Figure 5-106, Cont'd. Mean Monthly Precipitation: June-July.

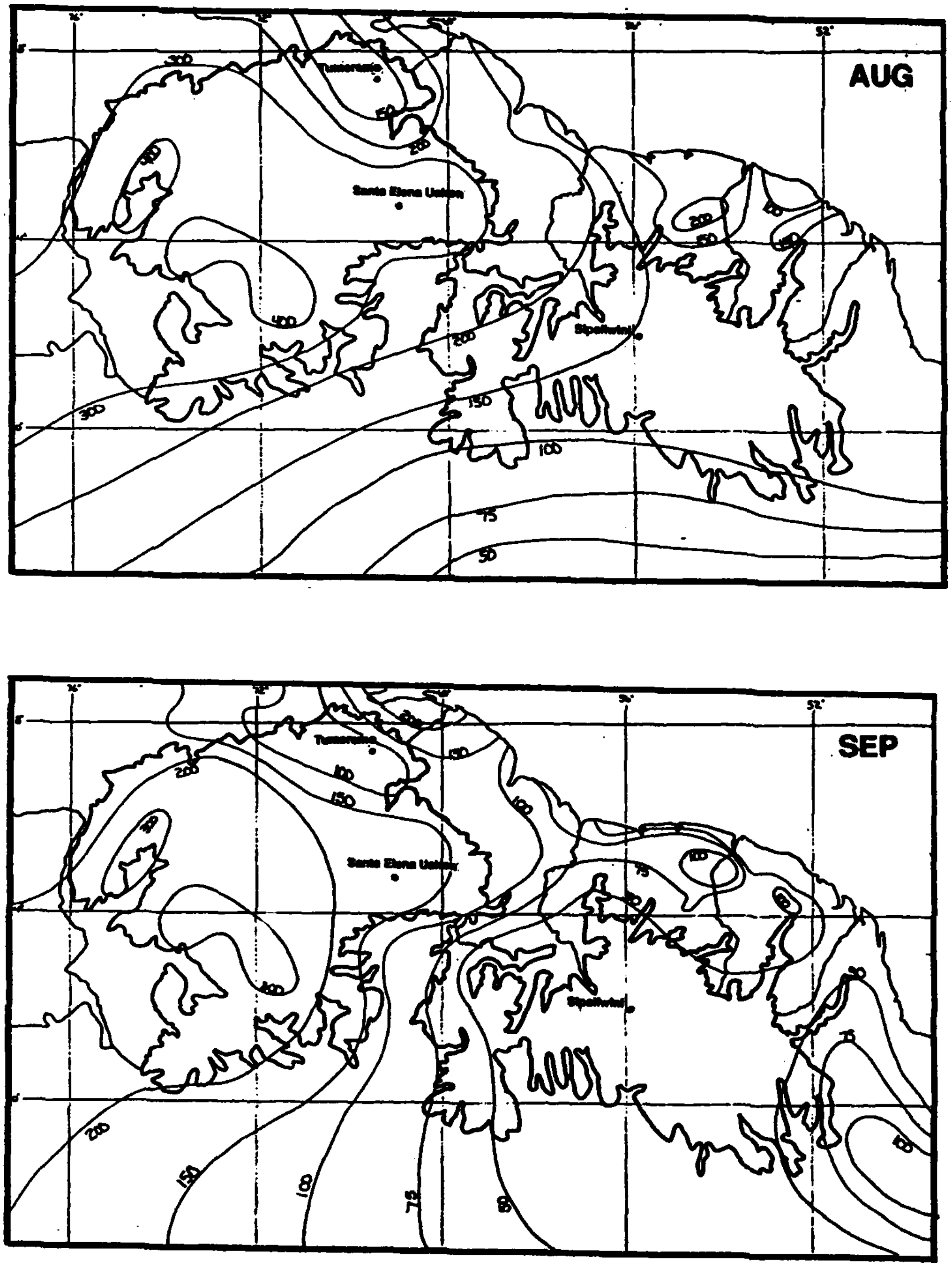


Figure 5-106, Cont'd. Mean Monthly Precipitation: August-September.

GENERAL WEATHER. Southeasterly trades from the South Atlantic High move progressively south of the Guyana Highlands during the transition. Unlike the Amazon and the Guyana Coastal Plains, the southeast trades here provide the "rains" regime. Their retreat, along with the southward movement of the Monsoon Trough, ends the wet season. Strengthening subsidence inversions in the northeast trades that follow the Monsoon Trough south soon override the effects of rugged relief. Aiding the process is the steadily decreasing sun angle. Trough movement is known to lag the solar cycle by 2 to 3 months. Satellite imagery indicates that a new "Monsoon Trough" forms in the extreme northern Amazon Basin in late September in response to southward movement of the old (or oceanic) Monsoon Trough, which does not, apparently, cross the Guyana Highlands intact. This sequence is shown in Figure 5-105.

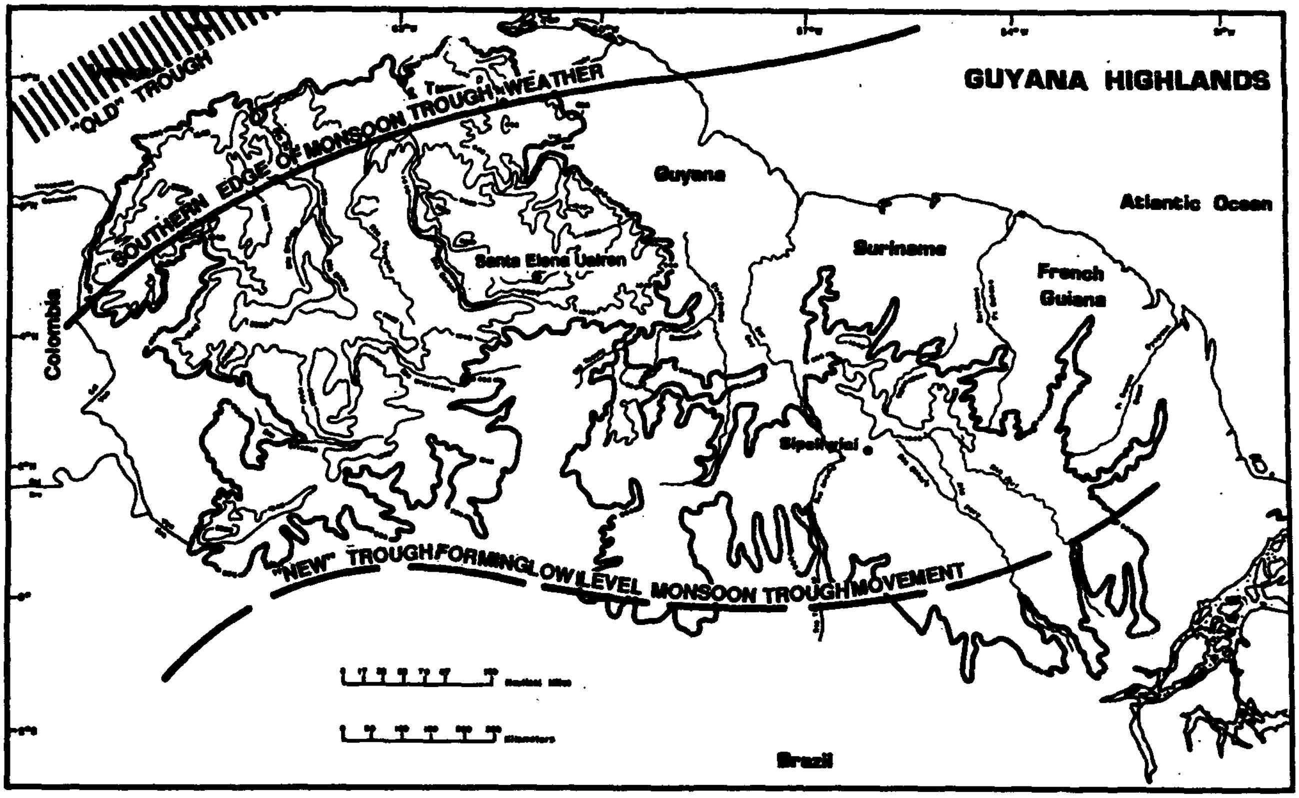


Figure 5-107. Low-Level Monsoon Trough Movement.

SKY COVER. In the immediate area of the weakening Monsoon Trough, sunrise finds widespread overcast valley stratus decks up to 2,500 feet (765 meters). Fog may or may not occur underneath these decks depending on whether winds are upslope or downslope, and whether or not precipitation is occurring. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus. Isolated heavy cumulus may also be found along southeastern-facing ridges. Tops are variable, ranging from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 1000 LST, the stratus has dissipated and heavy cumulus begins to form along mountain ridges and over flat-topped mesas above 3,500 feet (1,070 meters). By 1200 LST, most ridges and mesa tops have towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, numerous thunderstorms--some strong--occur over the entire region, dissipating after sunset. There are showers by late evening. Stratus decks form in valleys after midnight.

In the northeasterly trade winds, patchy low stratus decks form near dawn in low-lying valleys, dissipating by 0900 LST. Isolated cumulus forms over ridge lines and mesas by 1000 LST, with bases at 3,500 feet (1,070

meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus over the higher mountains or mesas builds to 15,000 feet (4.6 km) wherever local heating and/or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset.

Worse conditions--typical of the wet season--occur over the eastern portions of the Highlands with the remnants of trade wind surges or mesoscale convective complexes that affect the Guyana Coast Plains (which see).

WINDS. Gradient flow changes from east-southeasterly at 10 to 15 knots to east-northeasterly at 10 to 15 knots as the northeast trades set in. Surface flow varies with terrain.

THUNDERSTORMS. Thunderstorms are found along the windward sides and crests of mountain ridges in those areas still affected by the Monsoon Trough. Isolated thunderstorms occur over the eastern Highlands with trade wind surges or mesoscale convective complexes.

PRECIPITATION. October rainfall ranges from 5.9 inches (150 mm) in southwestern French Guiana to 3.9 inches (100 mm) in southern Venezuela. See Figure 5-106.

TEMPERATURE. Temperature varies with altitude. At lower elevations, highs are 84 to 88°F (29 to 32°C); lows from 72 to 77°F (22 to 24°C). In the highest mountains, highs are 50 to 60°F (10 to 15°C) as skies clear; lows are 39 to 45°F (4 to 7°C).

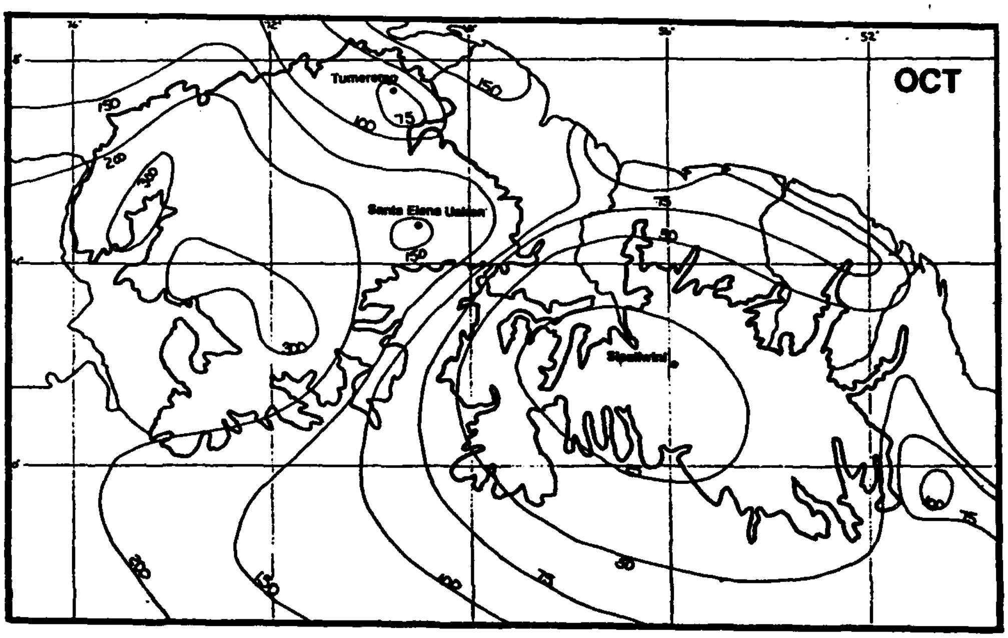


Figure 5-108. Mean Precipitation: October.

GENERAL WEATHER. When considering dry season weather here, users are reminded that the Guyana "Highlands" are better described as "mountains."

SKY COVER. Isolated cumulus forms over ridge lines by 1000 LST, with bases at 3,500 feet (1,070 meters). Vertical development is capped by the trade wind inversion at 6,500 to 7,500 feet (1,980 to 2,300 meters). Only very isolated heavy cumulus over the higher mountains or mesas builds to 15,000 feet (4.6 km) wherever local heating and or convergence can overcome the subsidence inversion. Clouds clear rapidly after sunset. Refer to Figures 5-100, 5-101, and 5-102 for typical valley ceiling and visibility conditions.

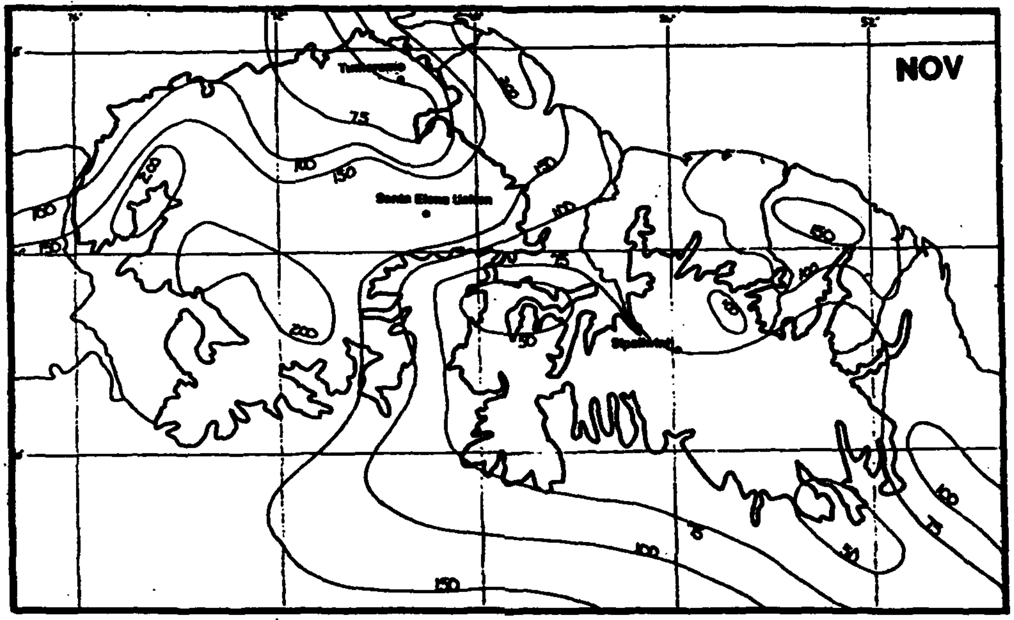
Worse conditions--typical of the wet season--can occur over eastern portions of the Highlands when the remnants of trade wind surges or mesoscale convective complexes affect the Guyana Coastal Plains (which see). Dawn sees widespread overcast valley stratus decks up to 2,500 feet (765 meters). Fog may or may not occur underneath these decks depending on whether winds are upslope or downslope, and whether or not precipitation is occurring. Above 2,500 feet (765 meters), skies are usually clear, with only patchy altocumulus/altostratus or cirrostratus/cirrus. Isolated heavy cumulus may also be found along southeastern facing ridges. Tops are variable, ranging from 8,000 to 15,000 feet (2,440 to 4,570 meters). By 1000 LST, the stratus has dissipated and heavy cumulus begins to form along mountain ridges and over flat-topped mesas above 3,500 feet (1,070 meters). By 1200 LST, most ridges and mesa tops see towering cumulus or cumulonimbus with bases at 4,000 feet (1,220 meters) and tops from 15,000 to 40,000 feet (4.6 to 12.2 km). By 1400 LST, numerous thunderstorms--some strong--occur over the entire region, dissipating after sunset. There are showers by late evening. Stratus forms in valleys after midnight.

WINDS. Gradient flow changes from east-southeasterly at 10 to 15 knots to east-northeasterly at 10 to 15 knots as the northeast trades set in. Surface flow varies with terrain.

THUNDERSTORMS. Thunderstorms are found along the windward sides and crests of mountain ridges in those areas still affected by the Monsoon Trough. Isolated thunderstorms occur with trade wind surges or mesoscale convective complexes over the eastern Highlands.

PRECIPITATION. Rainfall ranges from 20.5 inches (525 mm) in southwestern French Guiana to 24.6 inches (625 mm) in southern Venezuela. See Figure 5-107.

TEMPERATURE. Temperature varies with altitude. At lower elevations, highs are 84 to 88°F (29 to 32°C); lows from 72 to 77°F (22 to 24°C). Over the highest mountains, highs are 50 to 60°F (10 to 15°C) as skies clear; lows are 39 to 45°F (4 to 7°C).



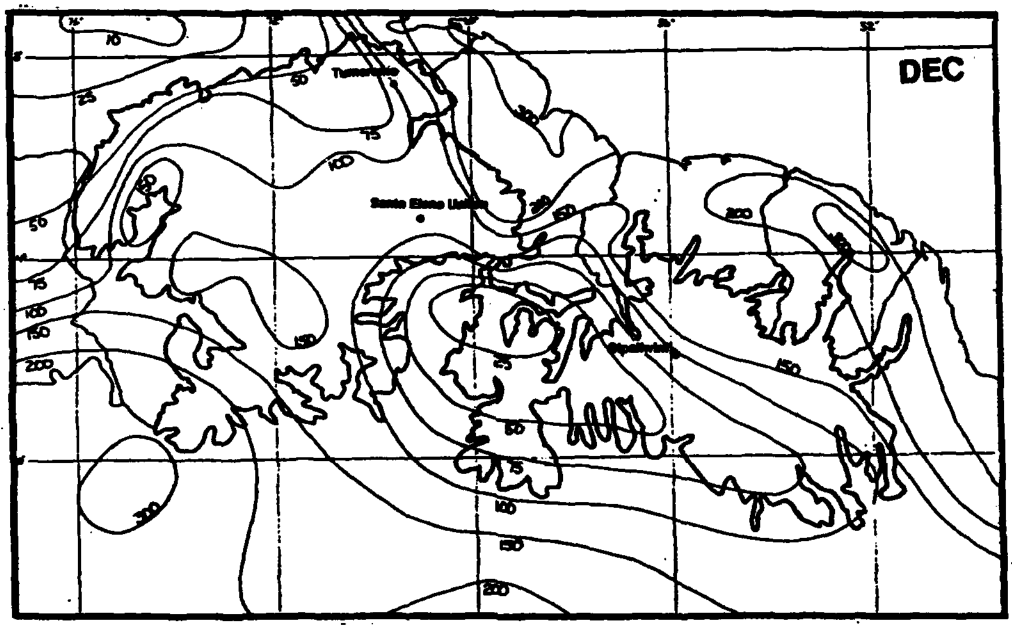
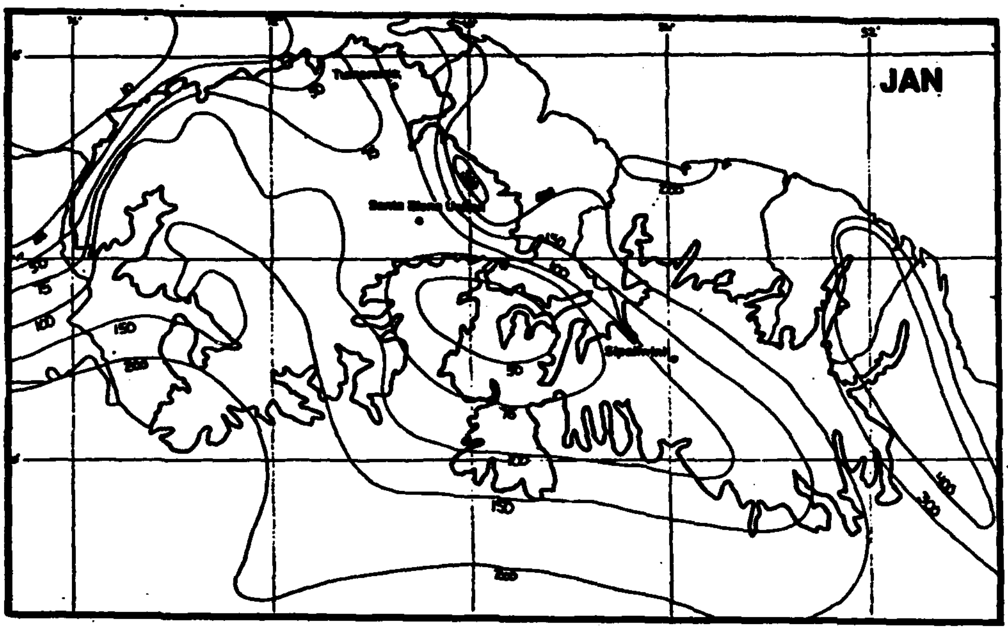


Figure 5-109. Mean Monthly Precipitation: November-December.



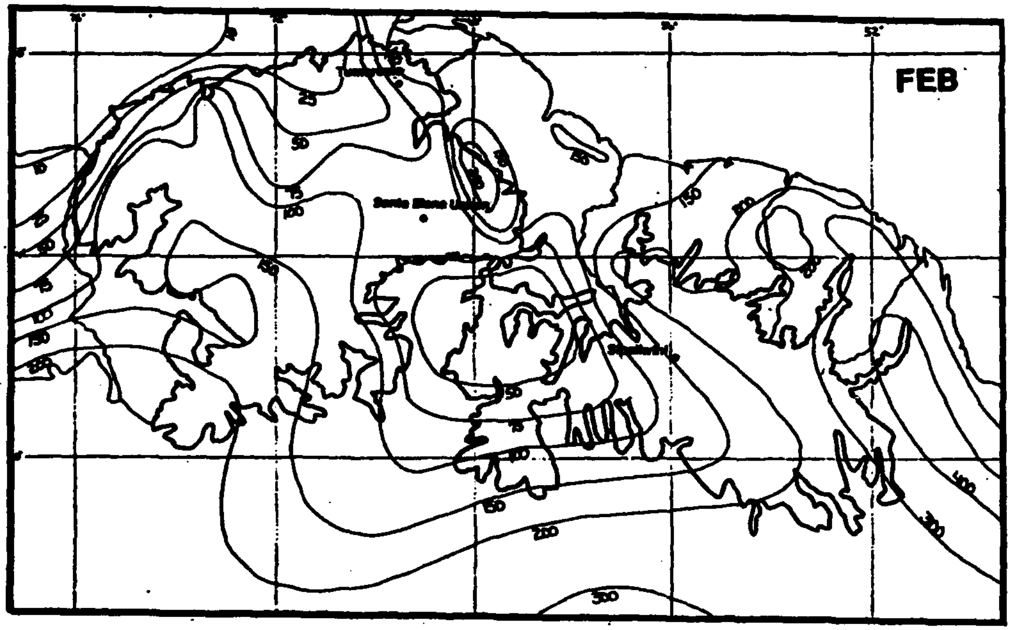


Figure 5-109, Cont'd. Mean Monthly Precipitation: January-February.

5.9 THE NORTHERN AMAZON BASIN

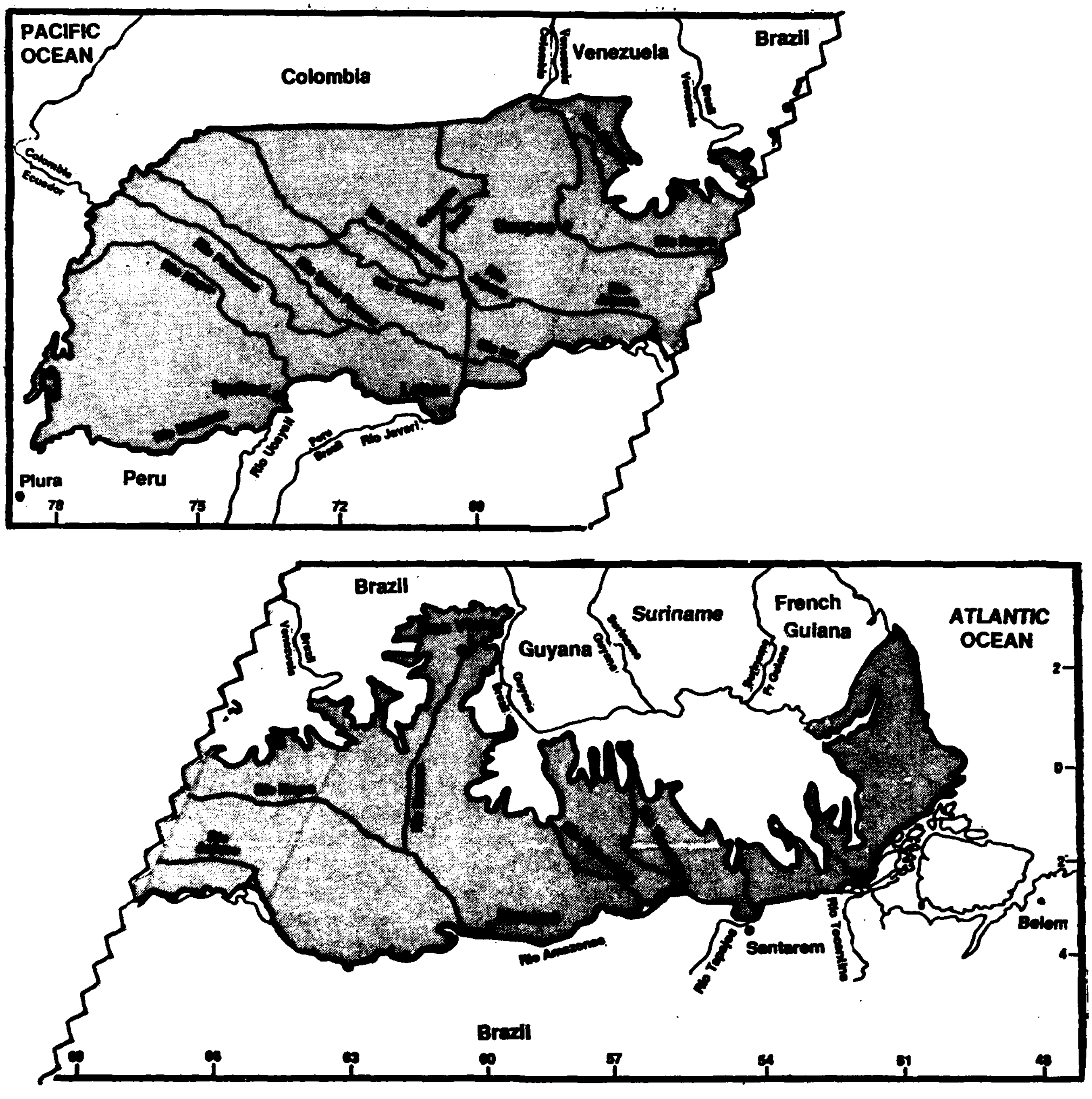


Figure 5-110. The Northern Amazon Basin. This region extends from the Amazon River and its main westward tributary (the Rio Maranon) northward and westward to the Guyana, Colombian, and Ecuadorian Highlands. It is characterized by broad plains and rolling hills cut by large rivers. Elevations are less than 1,640 feet (500 meters). The entire area is covered by jungle or tropical rain forest.

NORTHERN AMAZON BASIN GEOGRAPHY

BOUNDARIES. The region described as the Northern Amazon Basin is bounded as follows:

On the south by the mouth of the Amazon River westward to Nauta, Peru (4° 30' S, 73° 30' W); westward from Nauta along the Rio Maranon to 5° S, 78° 38' W, then west along latitude 5° S to the Pacific Ocean.

On the west from the 3,280-foot (1,000-meter) contour line at the Rio Maranon, sloping down to the 2,500-foot (760-meter) contour line at 2° N, 75° 10' W.

On the north from the 2,500-foot (760-meter) contour line at 2° N, 75° 10' W east-northeastward to the Colombia-Venezuela border at 3° N. Then eastward along the ridge separating the Orinoco and Amazon river drainages to 66° W and south along the 66° W longitude line to the 1,640-foot (500-meter) contour line on the north side of the Venezuela-Brazil frontier. From this point (about 2° N, 66° W) southwest, then south, along the 1,640-foot (500-meter) contour line on the eastern side of the Rio Negro into northern Amazonas State, Brazil. Eastward from this point along the 1,640-foot (500-meter) contour line to the Amazon Delta on Brazil's Atlantic coast.

On the east by the Atlantic Ocean.

TERRAIN. As of 1989, even the latest aeronautical charts prepared by the United States Defense Mapping Agency indicated that the terrain of the northern Amazon Basin, especially that portion west of Manaus (at about 3° S, 60° W), was still not completely charted. This was particularly true of the areas just south of the Guyana Highlands.

The vast tropical rain forest in the Amazon Basin stretches almost 1,950 miles (3,125 km) from the Atlantic Ocean to the Equadorian, Colombian, and Guyanian highlands. Its river systems drain much of northern South America. All rivers and streams in the system eventually join the Amazon.

Most of the basin lies below 656 feet (200 meters), but higher elevations are found on the western and northern fringes as terrain rises towards the Guyana, Colombian, and Ecuadorian highlands.

Rivers are wide and meandering except along the eastern slopes of the Andes, where currents are surprisingly fast, running at 3 to 7 knots. The primary river is the Amazon. Its massive main stream is formed at Nauta in eastern Peru where the Maranon and the Ucayali, both draining the Peruvian Andes, join its growing waters.

Moving eastward towards Manaus (3° S, 60° W), the major tributaries flowing from the north into the Amazon are the Ica, the Japura, and, just west of Manaus, the Negro. The Negro is navigable upstream from Manaus to at least as far as Tapuruquara (00° 25' S, 65° 02' W). The Amazon proper is navigable upstream by river steamers at least to Iquitos (3° 45' S, 73° 12' W) in eastern Peru. Manaus itself can be reached by ocean-going vessel.

From Manaus eastward to the Atlantic, the primary tributaries reaching the Amazon from the north are the Uatuma, the Nhamunda, the Lake Erepecu-Lake Batata system, the Curua, the Maicuru, the Paru, and the Jari. East of the Xingu, a very large tributary located about halfway between the mouths of the Paru and the Jari flows into the Amazon from the south.

The Amazon splits into two main channels as it flows to the Atlantic, but not until it reaches some 345 miles (550 km) inland from the Atlantic. Much like the Mississippi Delta, there are numerous islands and side channels from here to the ocean. The main, or northern, branch is considered to be the Amazon proper. The southern branch has no specific name, but it flows into Viera Grande Bay. From this point eastward (this bay is connected to the northern, or "Amazon" branch), three main channels or "canals" (called "passes" on the Mississippi) flow into the Atlantic: these are the Northern, Perigoso, and Southern Canals.

VEGETATION. Dense mangrove swamp covers most of the immediate coastal area and extends inland to the point where the various mouths of the Amazon originate. Mangrove trees often reach heights of 100 to 150 feet (30 to 45 meters). Open water areas that are not a part of the actual mouth system are covered by swamp grass that grows to 2 to 5 feet (0.6 to 1.5 meters).

Most of the Amazon Basin is covered by tropical rain forest. Trees are broadleafed evergreen--there are no conifers typical of temperate latitude forests.

Tropical rain forests are normally "five-tiered." The topmost tier, called the "emergent layer," consists of isolated tall trees that reach heights of 130 feet (40 meters) or more. The second, or "canopy," tier, is a dense blanket of trees from o5 feet (20 meters) to 130 feet (40 meters) tall. The canopy tier effectively blocks most, if not all, sunlight from penetrating to lower tiers. The third, or "middle," tier, consists of a dense growth with tops ranging from 16 feet (5 meters) to 65 feet (20 meters). The middle tier often merges with the canopy tier. The fourth, or "shrub," tier, is a sparse growth of woody shrubs and small trees that does not exceed 16 feet (5 meters) in height. Growth is sparse because of the lack of sunlight at this level.

The fifth, or "ground," tier, consists of shade-tolerant herbs, ferns, and tree seedlings. No grass survives on the forest floor; at noon, sunlight here is less than 1% of that found above the canopy.

The rain forest's dense, broadleafed vegetation emits water vapor continuously. Research in the Amazon Basin shows that typical rain forests release almost half as much water vapor back into the atmosphere as they receive in the form of rain. For the meteorologist, this is not merely interesting--it is vitally important. The moisture content of air masses traveling over this region is continuously replenished. An air mass that rises over the highlands and mountains surrounding the northern Amazon Basin is virtually as moist as it was when it came onshore off the Atlantic Ocean. As a result, the tropical rain forest is found along eastern Andes slopes at elevations above 2,500 feet (760 meters).

NOTES ON AMAZON BASIN WEATHER AND CLIMATE

The meteorology and climatology of the Amazon Basin, especially west of Manaus and north into the Guyana Highlands, are even less well known than its terrain. Meteorological studies and long-term summarized climatic data are scarce. Surface weather reporting stations are few and widely separated; most are concentrated along rivers. There are even fewer upper-air stations, and they normally take only one observation a day.

Although the Brazilian portion of this region is receiving more attention--especially from Brazilian agencies concerned with Amazon development--even the Brazilian meteorological community admits that much research needs to be done. Very little data is available from eastern Peru and Ecuador, either. In any case, information on this area's weather and climate is much scarcer and harder to locate in the United States than in Brazil.

Despite the noted reservations, all available information and data sources, including extensive satellite imagery, have been used in the preparation of this study. Even so, readers should understand that these discussions must necessarily be considered provisional.

GENERAL WEATHER. The Amazon Basin from the mouth of the Amazon westward to Manaus (about 3° S, 60° W) has a well-defined wet season that lasts from January through May. West of Manaus, the wet season gradually increases in length until, from the western frontier of Brazil to the Andes foothills, there is no definable dry season. In view of the gradual transition westward, no attempt has been made to subdivide the region further. Specific differences between the two, however, are highlighted in the text.

Wind flow over the Amazon Basin is complex. Were northern South America flat, the trade winds would converge into the Monsoon Trough. However, the effects of the Guyana and Colombian Highlands are to diverge the flow below 5,000 feet (1,500 meters) into a "fan" west of Manaus. Winds on the northern side of this fan-shaped wind field recurve northwestward around the west side of the Guyana Highlands into the Colombian Highlands. This anticyclonic curvature, however, is not enough to overcome the combined effects of forced lift, heating, upper-level outflow, and persistent convergence into the Monsoon Trough. Winds in the center of the fan move westward and west-southwestward across rising terrain until they reach the eastern Andes foothills. Winds on the fan's southern side, which would normally diverge towards the southwest and south, are constrained by rising terrain south of the Amazon River to move towards the west-southwest. Chapter 2 discusses this phenomenon in more detail.

Upper-level winds are highly sensitive to movements of the Bolivian Anticyclone which, formed in late November and December, provides the exhaust mechanism for the sustained heavy convection typical of the Amazon Basin wet season. By April, the high has moved northward to the western Amazon basin and weakened dramatically. See Figures 5-111 (Belem) and 5-112 (Manaus and Iquitos) for mean monthly upper-level wind directions. Elevations shown are 10,000 feet (3 km), 20,000 feet (6.1 km), and 30,000 feet (9.3 km). The 30,000-foot wind directions are particularly sensitive to movements of the Bolivian Anticyclone.

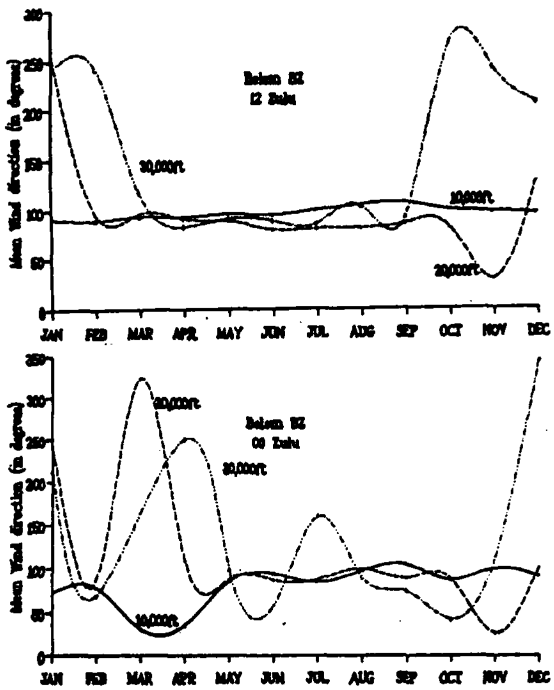


Figure 5-111. Mean Upper-Level Winds: Belem, Brazil.

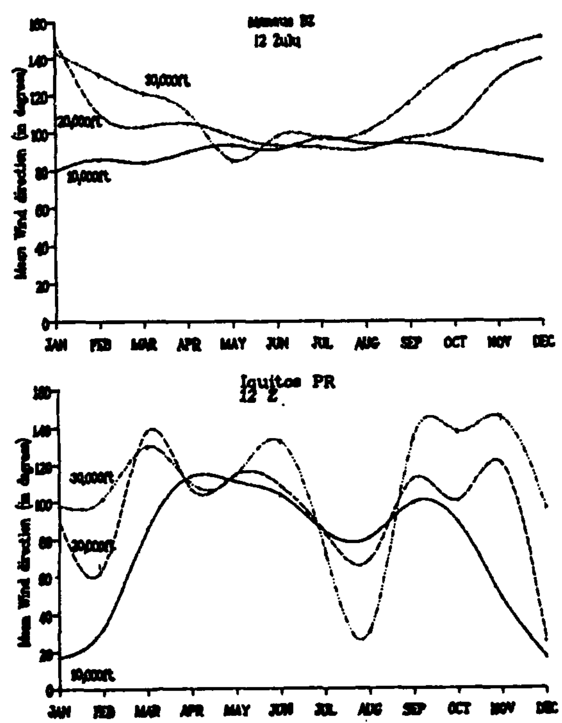


Figure 5-112. Mean Upper-Level Winds: Manaus, Brazil, and Iquitos, Peru.

Land-sea breezes along the Atlantic Coast are thought by some Brazilian and American meteorologists to be the secondary cause of enhanced convection lines in the Amazon Basin. Although very well developed examples have been tracked as far as Manaus, we believe such cases occur in conjunction with some type of low-level convergence.

Mesoscale convective complexes occur in the central and western Amazon Basin during the wet season, lasting for 18 to 36 hours and reaching the western Amazon basin. During May and June, some have become stationary over the extreme western parts of the Amazon Basin, later apparently recurving eastward against the flow on the south (poleward) side of the Monsoon Trough. Such cases are rare as well as controversial.

SKY COVER. In the absence of trade wind surges or enhanced convective lines, dawn on the immediate Atlantic coast sees 3-5/10 stratus and cumulus with bases between 1,500 and 2,000 feet (455 and 610 meters). Patchy shallow ground fog forms in swamps protected from the open ocean. Towering cumulus--often in lines--builds 20 to 40 miles offshore and moves onshore between 0800 and 1000 LST to produce moderate to occasional heavy rain showers. By 1100 LST, trade wind cumulus and stratocumulus form, with bases between 1,500 and 2,500 feet (455 and 760 meters); tops are usually at 5,000 to 7,000 feet (1,525 to 2,135 meters). Scattered light showers fall during the afternoon. Clouds clear after sunset. Patchy stratus and stratocumulus form in late evening, becoming 3 to 5/10 by dawn. Visibilities outside showers remain good except along rivers and in coastal swamps during early morning. Mean thunderstorm, precipitation, and temperature data for Belem, Brazil, is shown in Figure 5-113, while Figure 5-114 gives mean ceiling and visibility frequencies for Santarem, Brazil. Belem and Santarem are representative of conditions along and 50 miles inland from the coast.

BELEM AP BRAZIL

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	24 HR PRECIP
JAN	94	80	69	13.4	87	73	8	3.8
FEB	93	80	68	16	86	73	8	4.8
MAR	94	80	68	17.1	86	74	7	3.9
APR	93	81	70	13.5	86	74	7	3.4
MAY	94	81	68	11.3	88	74	7	4.9
JUN	94	81	68	6.9	89	73	7	2.6
JUL	93	81	65	5.7	89	73	7	2.8
AUG	95	81	68	6	89	73	7	2
SEP	94	81	67	4.6	89	73	7	1.8
OCT	94	82	68	3.6	89	73	6	1.9
NOV	95	82	67	3.4	89	73	5	1.6
DEC	96	81	67	6.8	89	73	7	3.1

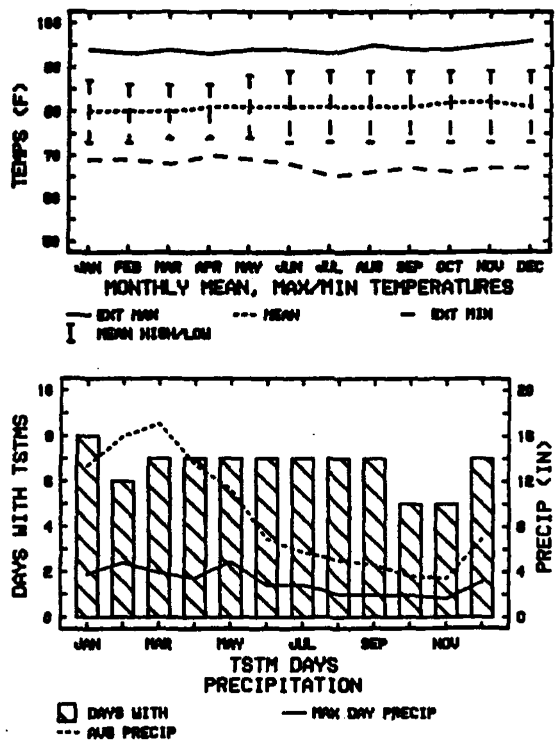


Figure 5-113. Thunderstorms, Precipitation, and Temperature: Belem, Brazil.

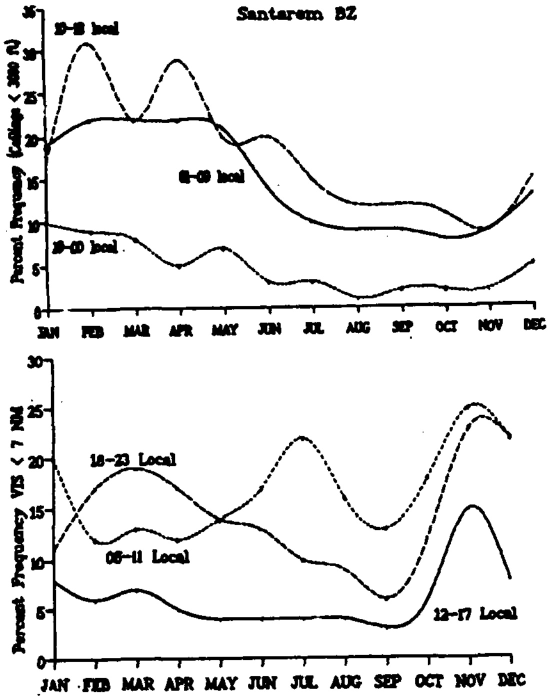


Figure 5-114. Percent Frequency Ceiling and Visibility <3,000/7: Santarem, Brazil.

For 50 to 75 miles (80 to 120 km) inland from the Atlantic (and extending to Manaus), the typical sky cover cycle is different from that illustrated by data for Belem and Santarem. Increased daytime heating results in a typical continental cloud cover cycle: cumulus formation during mid-morning, heavy cumulus and cumulonimbus by early afternoon, precipitation maximums between 1400 and 1900 LST, and clearing by early evening.

Depending on their distance from shore, the towering cumulus lines that form off the Atlantic coast near dawn arrive onshore between late afternoon and very early the next morning. Heavy showers (thundershowers if arrival time is during afternoon or early evening) accompany their passage. Bases in the heaviest showers are between 500 and 1,000 feet (150 and 305 meters); visibilities go as low as 0.5 mile (800 meters). Tops range from 25,000 to 50,000 feet (7.6 to 15.2 km). At dawn, patchy stratus and cumulus form, with bases at 1,000 to 1,500 feet (305 and 455 meters). By 0900 LST, sky cover has become 5-7/10 cumulus and towering cumulus with bases at 2,000 to 2,500 feet (610 to 760 meters) and tops at 5,000 to 8,000 feet (1,525 to 2,500 meters). By 1100 LST, isolated towering cumulus reaches 25,000 feet (7.6 km); by 1400 LST, scattered towering cumulus and isolated cumulonimbus tops reach from 25,000 to 45,000 feet (7.6 to 13.7 km). Layered altocumulus, altostratus, cirrus, and cirrostratus surround cumulonimbus. Very heavy rain showers fall from these buildups, with visibilities lowering to 0.25 mile (400 meters).

Skies begin to clear by sunset. By mid-evening only cumulus and stratocumulus, with bases 1,500 to 2,500 feet (455 and 760 meters), remain. Visibilities throughout this diurnal cycle remain good; the only restrictions are heavy showers or the patchy fog that forms near dawn along rivers and lakes but dissipates rapidly after sunrise. Figure 5-115 gives ceiling and visibility data for Boa Vista, Brazil; Figures 5-116 and 5-117 give similar data for Manaus. These stations are representative of the central portion of the region.

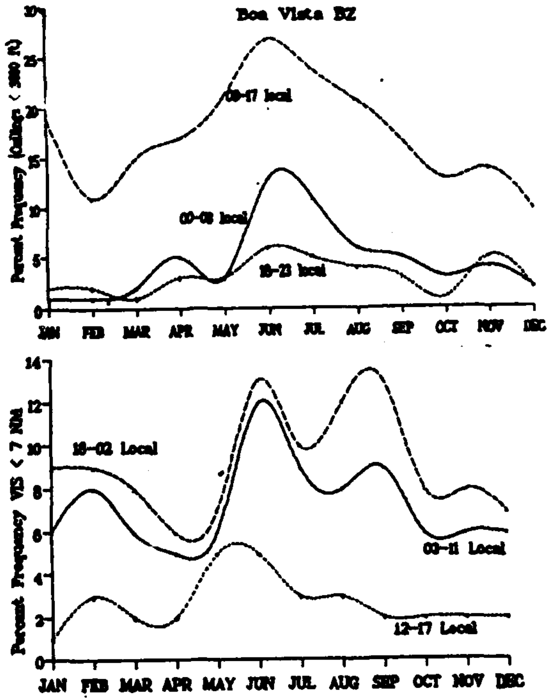


Figure 5-115. Percent Frequency Ceiling and Visibility <3,000/7: Boa Vista, Brazil.

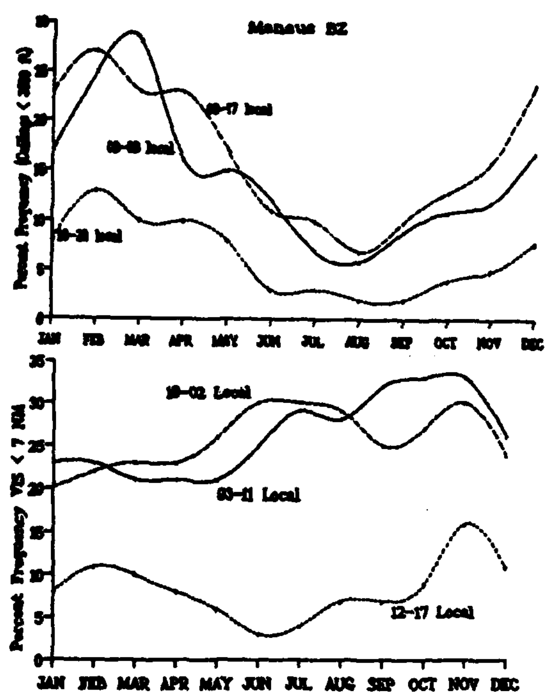


Figure 5-116. Percent Frequency Ceiling and Visibility <3,000/7: Manaus, Brazil.

MANAUS AP BRAZIL

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	AVG MAX	AVG MIN	TSTM DAYS	24 HR PRECIP.
JAN	98	80	68	10.5	88	73	4	3.8
FEB	100	80	66	8.7	88	70	3	4
MAR	97	81	67	10.6	87	70	4	5.1
APR	96	81	69	10.5	87	71	5	4.8
MAY	95	81	67	7.8	87	73	8	4.1
JUN	95	81	66	3.9	87	75	4	2.0
JUL	96	81	64	1.8	87	74	3	2.7
AUG	98	82	67	1.5	88	74	4	2
SEP	98	82	68	2.4	90	74	5	2
OCT	100	82	69	4.3	88	73	7	3.6
NOV	98	82	66	6.2	89	74	7	3.9
DEC	101	81	67	8.5	87	72	6	3.3

MANAUS AP BRAZIL

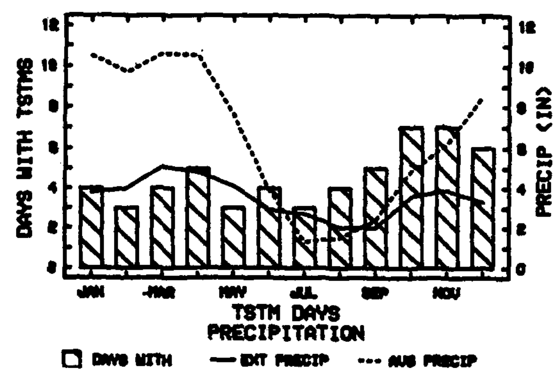
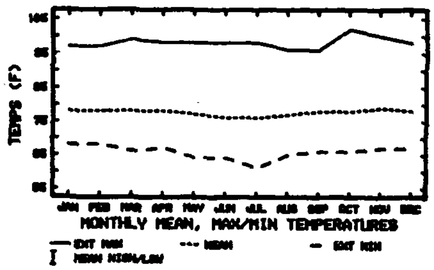


Figure 5-117. Thunderstorms, Precipitation, and Temperature: Manaus, Brazil.

Thunderstorms increase to reach a maximum near the Peru-Colombia-Brazil borders. In eastern Peru and Colombia, ceilings and visibilities begin to deteriorate. At the eastern Andes and Guyana Highland foothills, cloud cover becomes almost overcast from late morning to early evening. Bases average from 1,000 to 2,000 feet (305 to 610 meters); tops range from 5,000 to 12,000 feet (1,525 to 3,660 meters). Rain showers and intermittent rain, restricting visibilities to 3 to 5 miles (4.8 to 8 km), become more common. Near the eastern Andes and Guyana Highlands foothills, clouds often form a solid overcast at 1,500 to 2,000 feet (455 to 610 meters) MSL; terrain above 2,000 feet MSL is hidden in perpetual cloud, rain, and mist. Tops range from 5,000 to 15,000 feet MSL (1,525 to 4,570 meters). Heavy cumulus along north-south ridge lines reaches 18,000 to 25,000 feet (5.9 to 7.6 km). Isolated cumulonimbus--primarily in the afternoon--reaches 40,000 feet (12.2 km). Layered altocumulus, altostratus, cirrus, and cirrostratus surround cumulonimbus. Figure 5-118 (Uaupes, Brazil, on the Rio Negro), Figure 5-119 (Letica, in extreme southeastern Colombia), Figure 5-120 (Piura, in extreme eastern Peru), and Figure 5-121 (Iquitos, in eastern Peru on the Amazon) give fairly representative samplings of weather conditions in the eastern Amazon Basin.

UAUPES BRAZIL

	EXT MAX	MEAN TEMP	EXT MIN	AVG PRECIP	TSTM DAYS	MAX DAY PRECIP
JAN	97	78	68	11.2	10	4.5
FEB	97	78	69	10.9	10	3.2
MAR	99	78	68	11.2	12	6.1
APR	98	78	67	10.4	9	3.9
MAY	98	77	64	12.9	7	4.1
JUN	98	76	64	9.6	8	3.3
JUL	98	76	61	9.2	10	6.2
AUG	96	77	65	7.8	15	2.4
SEP	96	78	68	6.9	13	2.8
OCT	102	78	68	6.5	12	4.4
NOV	100	78	67	7.5	12	4.2
DEC	98	78	67	10.6	10	3.9



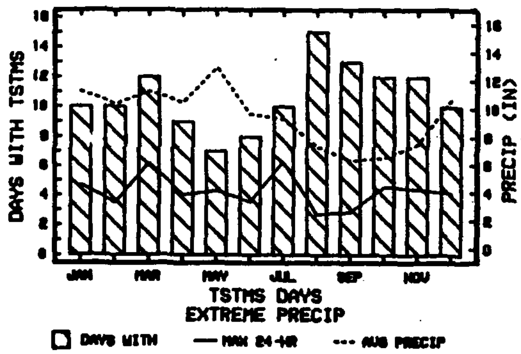


Figure 5-118. Thunderstorms, Precipitation, and Temperature: Uaupes, Brazil.

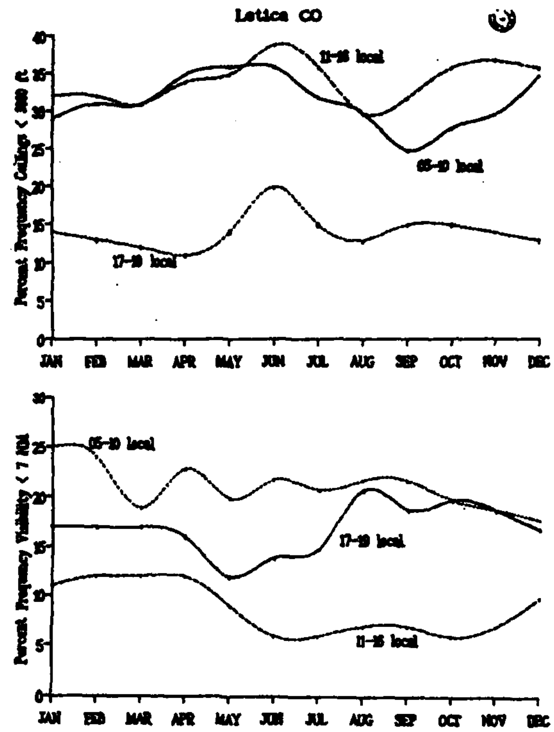


Figure 5-119. Percent Frequency Ceiling and Visibility <3,000/7: Letica, Colombia.

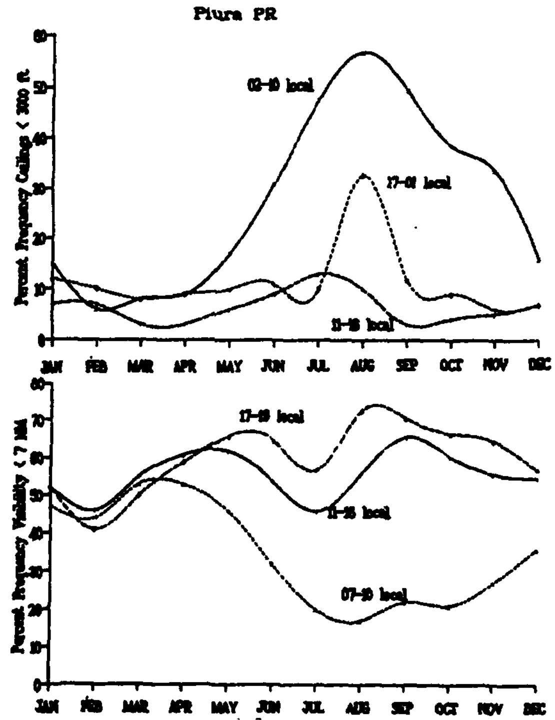


Figure 5-120. Percent Frequency Ceiling and Visibility <3,000/7: Piura, Peru.

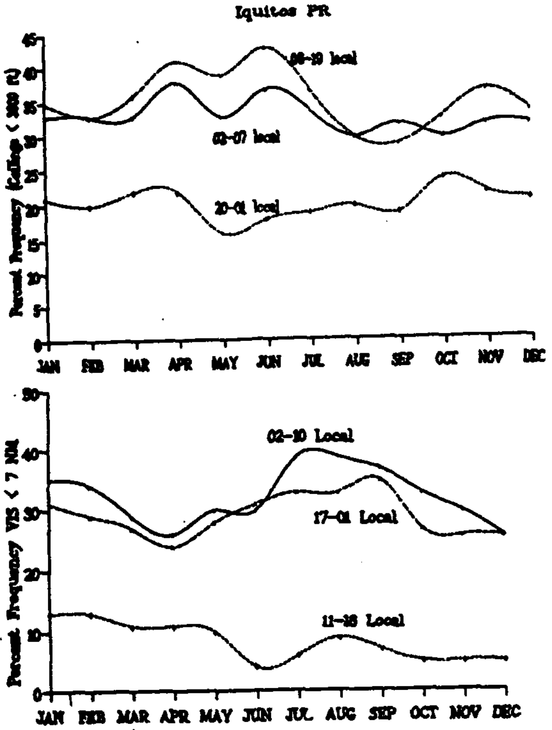


Figure 5-121. Percent Frequency Ceiling and Visibility <3,000/7: Iquitos, Peru.

Trade wind surges break the normal diurnal cycle that was discussed earlier. These surges often result in lines of towering cumulus and cumulonimbus stretching from the Amazon northward to the Guyana Highlands. Although these phenomena are referred to here as "squall lines," they do not much resemble the squall lines found in the mid latitudes. Although the heaviest rain in these tropical "squall lines" occurs with the cumulonimbus line, most precipitation occurs in the layered middle and high clouds east of the cumulonimbus line. As with temperate zone squall lines, movement is due primarily to propagation. Bases can be as low as 500 feet (150 meters); tops reach above 50,000 feet (15.2 km). Visibilities under the line can be near zero; those in the rain behind the cumulonimbus line average 2 to 4 miles (3.2 to 6 km). Figure 5-122a is a typical tropical "squall line" main cell in vertical cross section. Arrows show updrafts/downdrafts, environmentalwinds, and associated convergence/divergence Figure 5-122b is a cross-section through an entire squall line. The dark shading is the radar echo of the "bright band" in the trailing stratiform layers and the heavy thunderstorm cell core. Light shading shows other radar echoes. (Both figures after Hastenrath, 1985.)

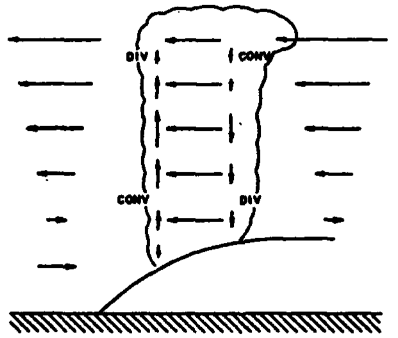


Figure 5-122a. Squall LineVertical Transect.

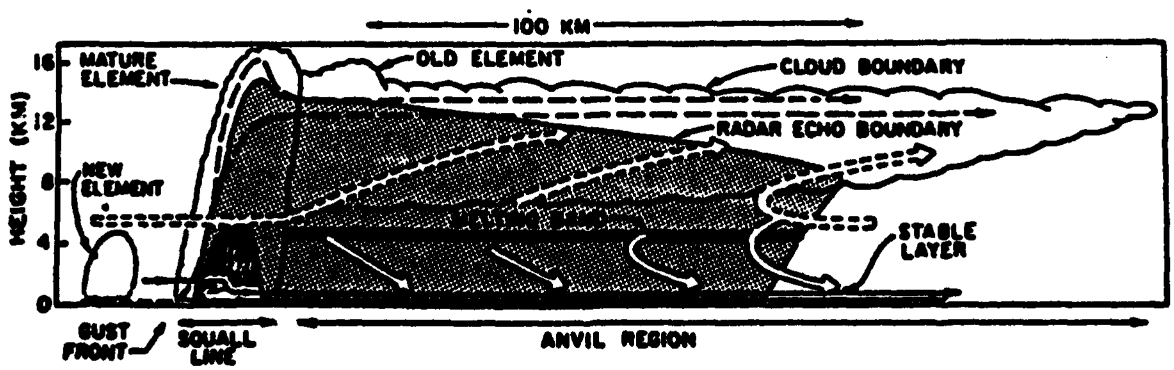


Figure 5-122b. Tropical Squall Line Cross-Section.

WINDS. 5,000-foot (1,500-meter) winds are from 070 to 090° at 15 to 20 knots. Surface winds along the immediate coast are northeasterly to east-northeasterly at 5 to 15 knots. Inland, daylight surface winds are northeasterly becoming easterly towards Manaus; speeds range from 5 to 15 knots. Nights see surface winds decoupling from gradient-level speeds and becoming nearly calm. West of Manaus, surface winds become easterly to southeasterly at 5 to 10 knots as the northeasterly trades diverge. In the immediate foothills of the Andes and the Guyana Highlands, wind directions and speeds become highly variable and dependent on the interaction of terrain, gradient wind speed and direction, and mountain-valley influences. Winds at the intersection of several mountain valleys reflect a combination of several mountain valley effects with the immediate terrain and gradient winds.

THUNDERSTORMS. This is the thunderstorm season. Thunderstorms increase to a maximum near the Peru-Colombia-Brazil border, where cumulonimbus reaches to 40,000 feet (12.2 km). Layered altocumulus, altostratus, cirrus, and cirrostratus surround cumulonimbus. Some thunderstorms are severe; their primary surface signature is an area of "tree-blowdown" in the tropical forest, caused by microbursts similar to those found by Dr Fujita of the University of Chicago during his United States downburst research. Although there are no reliable statistics, occurrence rates similar to those of the Panamanian "chubisco" are probable. This would limit storm frequency to no more than 3 to 7 per wet season at any one location. Higher elevations--up to about 3,000 feet (915 meters)--are more vulnerable. These views fit Central American experience.

PRECIPITATION. Figure 5-123 shows mean monthly rainfall in the Northern Amazon Basin for January through May. The data was taken from the *Climatic Atlas of South America* published by the World Meteorological Organization. Although unusual for tropical zones, January-June rainfall in the western northern Amazon Basin is only slightly more than half the mean annual rainfall total. This is not the case in the central portion of the basin, and certainly not so in the eastern parts. Figure 5-123 probably gives the most reliable and complete rainfall information available for the interior of South America. It also shows the effects of the Monsoon Trough's passage on precipitation amounts, which vary inversely with distance from the Trough. Mean annual rainfall is just under 80 inches (2,000 mm) over the southern approaches to the Guyana Highlands; more than 125 inches (3,200 mm) in the Peruvian and Ecuadorian rain forests; and more than 155 inches (4,200 mm) in eastern Andean foothills near 3,300 feet (1,000 meters).

TEMPERATURE. Highs range from 68 to 75°F (20 to 23°C) in the Andes foothills to 86 to 90°F (30 to 32°C) in the Amazon Basin and 84 to 86°F (29 to 30°C) along the Atlantic Coast. Lows are from 64 to 72°F (18 to 21°C) in the Andes to 79 to 81°F (25 to 26°C) in the Amazon Basin and 75 to 79°F (23 to 25°C) along the coast. Downrush thunderstorm winds may temporarily drop temperatures by 10°F (6°C), but they quickly return to normal.

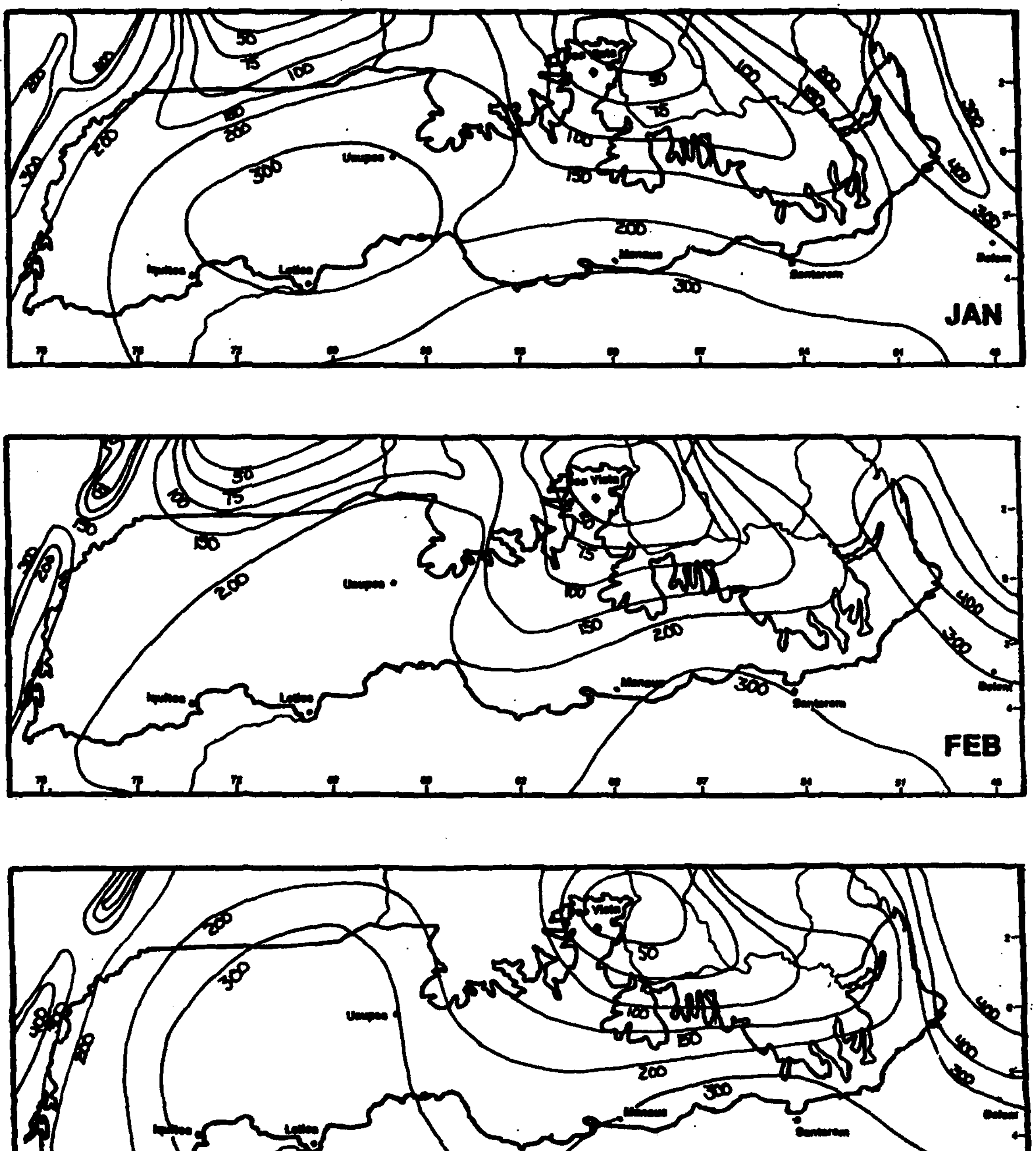


Figure 5-123. Mean Monthly Precipitation: January, February & March.

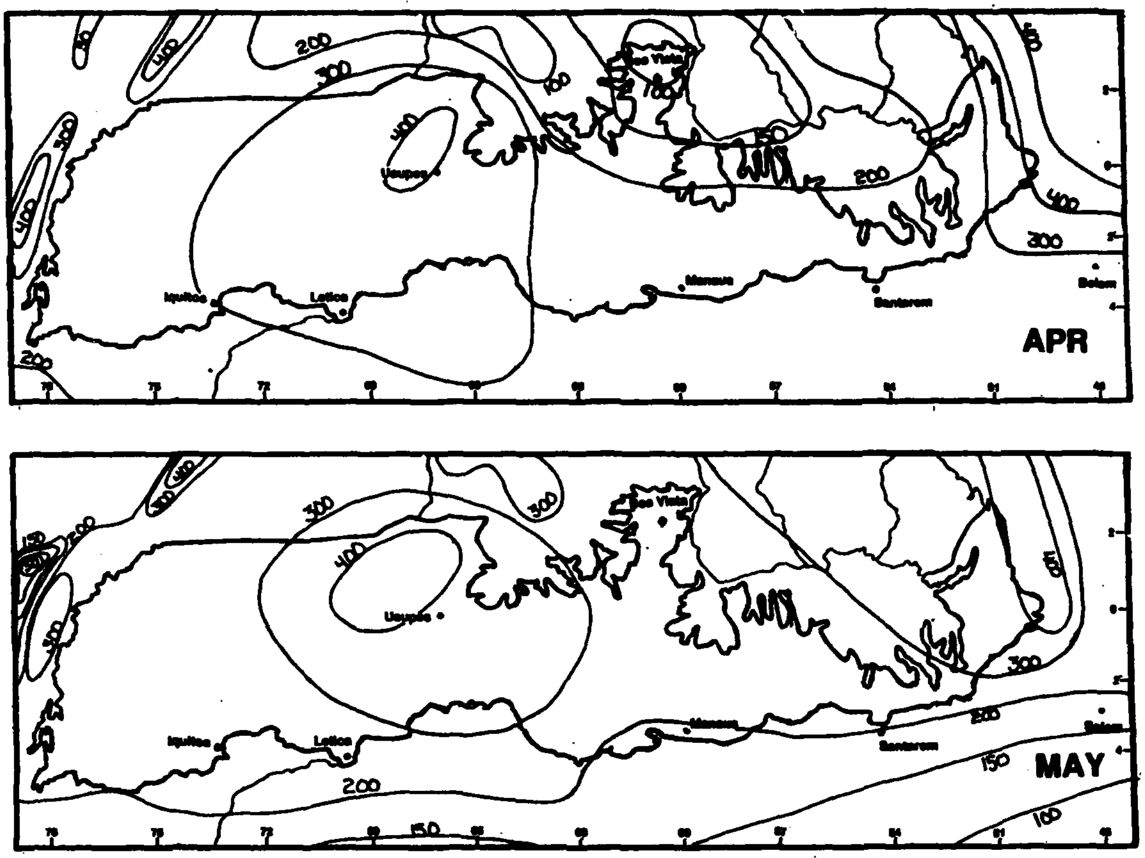


Figure 5-123, Cont'd. Mean Monthly Precipitation: April-May.

GENERAL WEATHER. Flow west of Manaus remains upslope; air moving westward continues to absorb water vapor from rivers and tropical rain forests. The combination yields a progressively longer wet season west of Manaus; by the time one reaches the Ecuador and Colombia borders, there is no dry season at all.

As South America enters the late southern hemisphere fall, sub-Antarctic cold fronts and the maritime polar air that follows them move northward out of central Argentina with greater frequency. By the end of June, the strongest of these cold surges reaches 5° S, or the southern Amazon Basin. Such outbreaks--the Brazilians call them "friagems"-- cause extensive overcast stratus decks in the "cold" air behind the cold front or surge line. Convection is almost totally suppressed. Surface temperatures drop below 68°F (20°C). Dissipation of the low-level cold air pool and stratus decks takes from 24 to 72 hours.

SKY COVER. In the absence of trade wind surges or enhanced convection lines, dawn on the immediate Atlantic coast sees 3-5/10 stratus and cumulus with bases between 1,500 and 2,000 feet (455 and 610 meters). Patchy shallow ground fog forms in swamps protected from the open ocean. Towering cumulus--often in lines--forms 10 to 20 miles offshore and moves onshore between 0800 and 1000 LST to produce light to occasionally moderate rain showers. By 1100 LST, trade wind cumulus and stratocumulus have formed, with bases between 1,500 and 2,500 feet (455 and 760 meters), usually with tops at 5,000 to 7,000 feet (1,525 to 2,135 meters). Very isolated light showers occasionally fall during the afternoon. Clouds clear after sunset. Patchy stratus and stratocumulus form in late evening, becoming 3 to 5/10 by dawn. Visibilities outside showers remain good except along rivers and in coastal swamps during early morning hours. Inland 15 to 25 miles (25 to 40 km) from the Atlantic and extending to Manaus, the typical sky cover cycle is the same as that for the wet season, which see.

WINDS. 5,000-foot (1,500-meter) winds are from 090 to 110° at 10 to 15 knots. Surface winds along the immediate coast are east-southeasterly at 5 to 10 knots. Inland, daylight surface winds are east- southeasterly becoming easterly towards Manaus, with speeds from 5 to 10 knots. At night, surface winds decouple from gradient level speeds and become nearly calm. West of Manaus, surface winds remain the same as in the wet season, which see.

THUNDERSTORMS. Thunderstorm frequency decreases dramatically. Very isolated severe thunderstorms occur, primarily along polar fronts; although no reliable occurrence statistics exist, fragmentary reports indicate 1 or 2 occurrences during this month-long transition.

PRECIPITATION. Figure 5-124, drawn from the WMO's *Climatic Atlas of South America*, shows mean June precipitation in the Northern Amazon Basin.

TEMPERATURE. Highs range from 68 to 75°F (20 to 23°C) in the Andes foothills to 87 to 91°F (30 to 32°C) in the Amazon Basin and 84 to 86°F (29 to 30°C) along the Atlantic Coast. Lows are from 64 to 72°F (18 to 21°C) in the Andes to 79 to 81°F (25 to 26°C) in the Amazon Basin and 75 to 79°F (23 to 25°C) along the coast.

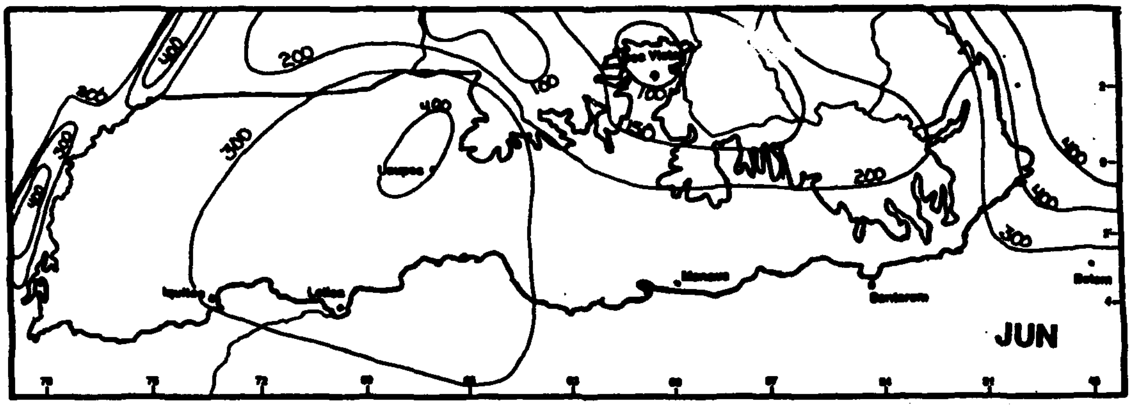


Figure 5-124. Mean Precipitation: June.

GENERAL WEATHER. Low-level wind flow in the Amazon Basin remains complex; adding to this complexity is the continuous absorption of water vapor from the numerous rivers and tropical rain forests. The combination yields a progressively longer wet season west of Manaus, enhanced by a lack of upper-air inversions that would "cap" convection. Figure 5-125 shows mean trade wind inversion heights--bottom and top--in the southeast trades over Belem. Note that a trade wind inversion is present only in the southeast trades, and then, as stated earlier, only near the coastline. By the time one reaches the Ecuador and Colombia borders, there is no dry season at all.

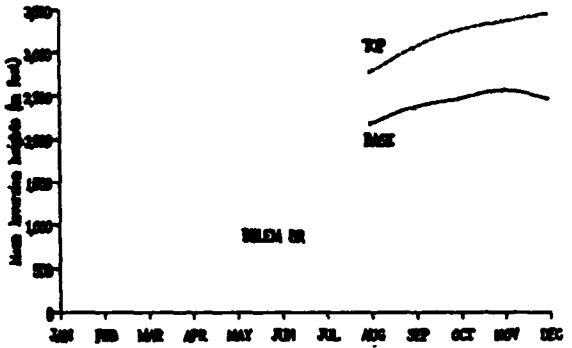


Figure 5-125. Mean Inversion Heights: Belem, Brazil.

By early July, strong Antarctic polar surges routinely reach the Equator. Extremely strong ones penetrate into southern Venezuela, and at least two have been documented as passing into the southern Caribbean. Such outbreaks--"friagems" to Brazilians--result in extensive convection along the front. Extensive overcast stratus decks occur in the "cold" air behind the cold front or surge line, with partial clearing during the day. Convection in the cold air is almost totally suppressed. Surface temperatures have dropped below 43°F (6°C). Dissipation of the low-level cold air pool and stratus decks normally takes from 48 to 96 hours, but surges lasting 5 days have been recorded. Reports from the late 19th century speak of two surges at Manaus, each of which exceeded 15 days.

Figure 5-126, from Parmenter, documents frontal continuity of such a surge as it moved north across South America in July 1975.

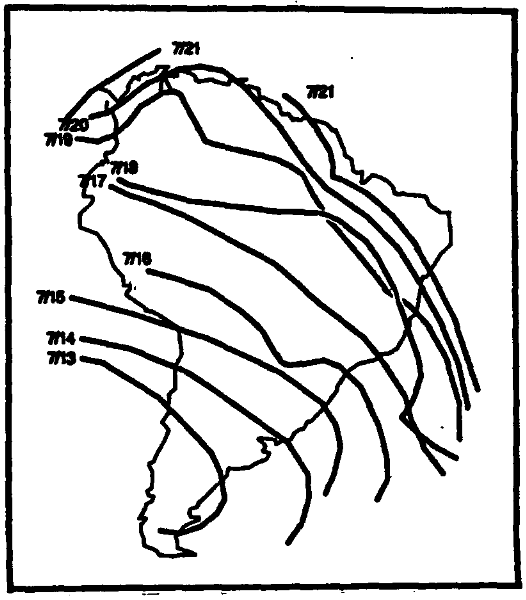


Figure 5-126. Polar Surge Continuity, 13-21 July 1975.

SKY COVER. Dawn on the immediate Atlantic coast sees 3-5/10 stratus and cumulus with bases between 1,500 and 2,000 feet (455 and 610 meters). Patchy shallow ground fog forms in swamps protected from the open ocean. Towering cumulus often forms in lines 20 to 40 miles offshore, moving onshore between 0800 and 1000 LST to produce light to moderate rain showers. By 1100 LST, trade wind cumulus and stratocumulus have formed, with bases between 1,500 and 2,500 feet (455 and 760 meters) and tops from 5,000 to 7,000 feet (1,525 to 2,135 meters). Isolated light showers fall during the afternoon. Clouds clear after sunset. Patchy stratus and stratocumulus form in late evening, becoming 3 to 5/10 by dawn. Visibilities outside showers remain good except along rivers and in coastal swamps during early morning hours.

Inland 25 to 35 miles (40 to 55 km) from the Atlantic and extending to Manaus, the typical sky cover cycle is different. Dawn sees clear skies to patchy stratus and cumulus with bases at 1,000 to 1,500 feet (305 and 455 meters). By 0900 LST, sky cover has become 2-3/10 cumulus and towering cumulus with bases at 2,000 to 2,500 feet (610 to 760 meters). Tops have reached 5,000 to 8,000 feet (1,525 to 2,500 meters). By 1100 LST,

very isolated towering cumulus clouds have reached 15,000 feet (4.6 km); by 1400 LST, isolated towering cumulus and a stray cumulonimbus have tops from 25,000 to 45,000 feet (7.6 to 13.7 km). Layered altocumulus, altostratus, cirrus, and cirrostratus surround the cumulonimbus. Moderate rain showers fall from these buildups, with lowest visibilities down to 1-2 miles (1,600-3,200 meters). Skies begin to clear by sunset; by mid-evening skies are mostly clear. Visibilities remain good throughout this diurnal cycle.

In eastern Peru and Colombia, ceilings and visibilities begin to deteriorate to conditions typical of the wet season, which see.

Two things break the diurnal cycle that has just been discussed. First, cold air penetrations result in a line (or lines) of towering cumulus and cumulonimbus ahead of and/or along the front. Behind the front, extensive layers of low stratus form in the shallow cold air dome that is normally less than 3,300 feet (1,000 meters) deep. These clouds can be thick enough to provide night-time drizzle, but normally break up during the day. Second, an occasional very rare upper-level cold air pool has been observed to drift northwestward from the South Atlantic. When it does, the result is widespread towering cumulus and cumulonimbus--tops to 45,000 feet (13.7 km)--within 300 miles of the cold pool center as it drifts northwestward. Given the extremely poor upper-air coverage in this region (only Manaus takes soundings, and only once a day), it is extremely hard to determine the frequency of cold pool passages. The satellite-observed passage of enhanced convective areas from southeast to northwest into southwestern Venezuela, however, seems to indicate that these may not be the rare events they were once thought to be. Two to three per dry season seems to be a reasonable assumption of frequency.

WINDS. 5,000-foot (1,500-meter) winds are from 090 to 110° at 10 to 15 knots. Surface winds along the immediate coast are southeasterly to east-southeasterly at 5 to 15 knots. Inland, daylight surface winds are east-southeasterly becoming easterly towards Manaus; speeds range from 5 to 15 knots. At night, surface winds decouple from gradient level speeds and become nearly calm. West of Manaus, surface winds are similar to those of the wet season, which see.

THUNDERSTORMS. Thunderstorms become much less frequent. So far as can be determined, severe thunderstorms during the dry season are almost unknown.

PRECIPITATION. Figure 5-127 shows mean monthly dry season rainfall. Note that in the western northern Amazon Basin, dry season rainfall is only slightly less than what would be found during 4 months of the wet season (see Figure 5-123 for wet season rainfall). But in central and eastern parts of the region (especially eastern), rainfall decreases significantly from the wet season. For example, some eastern stations have at least 1 month with total rainfall less than 1.2 inches (30 mm). The rainfall data in Figure 5-127 is probably the most reliable and complete available for the interior of South America. It also shows the effects of the southeasterly trades on precipitation.

TEMPERATURE. Highs range from 68 to 75°F (20 to 23°C) in the Andes foothills to 84 to 86°F (29 to 30°C) in the Amazon Basin and along the Atlantic Coast. Minimums range from 64 to 72°F (18 to 21°C) in the Andes to 75 to 79°F (23 to 25°C) in the Amazon Basin and along the coast. However, "friagems," as they are known to Brazilians and as mentioned earlier, drop temperatures into the middle 50s°F (12-13°C) routinely, but only temporarily.

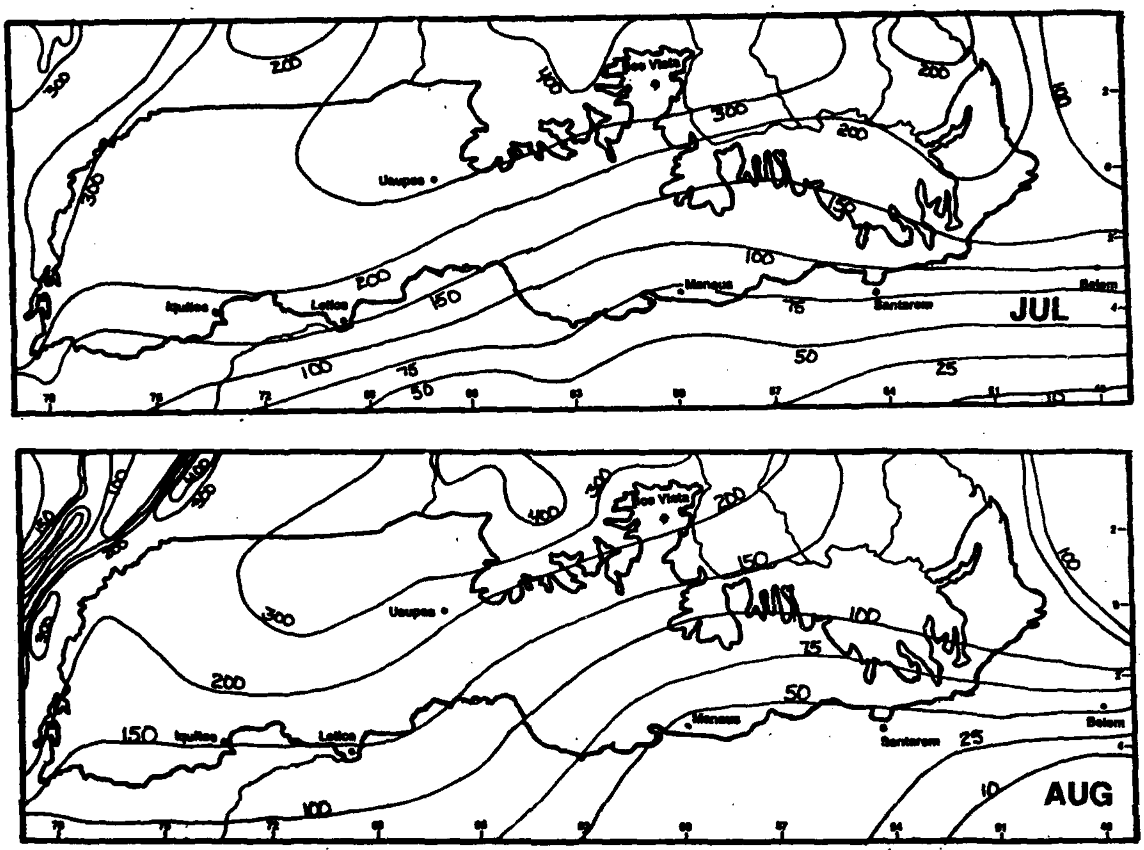


Figure 5-127. Mean Monthly Precipitation: July-August.

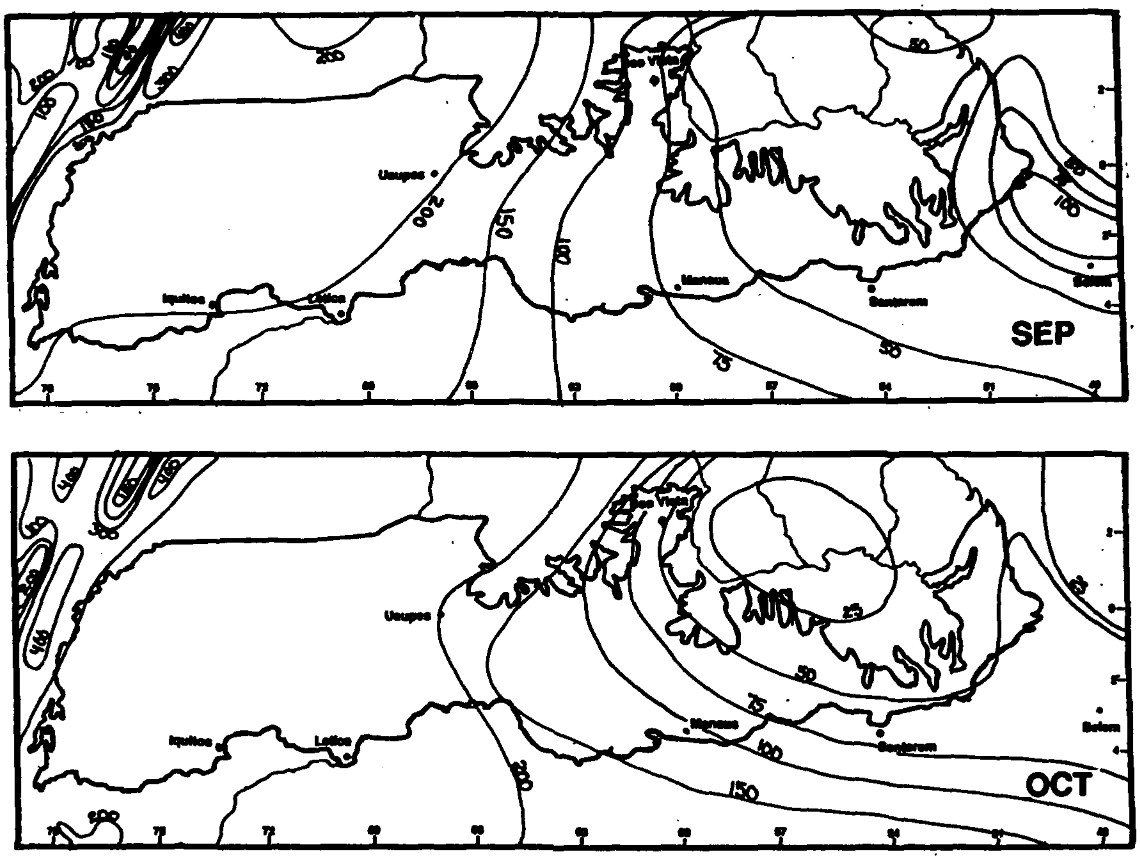


Figure 5-127, Cont'd. Mean Monthly Precipitation: September-October.

GENERAL WEATHER. The frequency of Antarctic polar surges decreases dramatically; they become almost unknown by the end of December. Total sky cover over the central and eastern Amazon Basin increases toward wet season maximums. Mesoscale convective complexes and trade wind surges make their first appearances by mid-December.

SKY COVER. In the absence of trade wind surges or enhanced convective lines, dawn on the immediate Atlantic coast sees 3-5/10 stratus and cumulus with bases between 1,500 and 2,000 feet (455 and 610 meters) at dawn. Patchy shallow ground fog forms in swamps protected from the open ocean. Towering cumulus, often in lines, forms 10 to 20 miles offshore, moving onshore between 0800 and 1000 LST to produce increasingly heavy rain showers in late November and early December. By 1100 LST, trade wind cumulus and stratocumulus have formed, with bases between 1,500 and 2,500 feet (455 and 760 meters) and tops at 5,000 to 7,000 feet (1,525 to 2,135 meters). Light to moderate showers occasionally fall during the afternoon. Clouds clear after sunset. Patchy stratus and stratocumulus form in late evening, becoming 3 to 5/10 by dawn. Visibilities outside showers remain good except along rivers and in coastal swamps during early morning hours.

Inland 30 to 60 miles (48 to 96 km) from the Atlantic and extending to Manaus, the typical sky cover cycle is different. Dawn sees skies that are clear to patchy stratus and cumulus with bases at 1,000 to 1,500 feet (305 and 455 meters). Lines of heavy cumulus and cumulonimbus that formed offshore in the early morning penetrate farther inland as the transition progresses. By late December they reach 200 miles (320 km) inland before dissipating. Otherwise, by 0900 LST sky cover has become 2-3/10 cumulus and towering cumulus with bases at 2,000 to 2,500 feet (610 to 760 meters) and tops at 5,000 to 8,000 feet (1,525 to 2,500 meters). By 1100 LST, very isolated towering cumulus reaches 15,000 feet (4.6 km); by 1400 LST, isolated towering cumulus (and perhaps a stray cumulonimbus) have tops from 25,000 to 45,000 feet (7.6 to 13.7 km). Layered altocumulus, altostratus, cirrus, and cirrostratus surround the cumulonimbus. Heavy rain showers fall from these buildups, with lowest visibilities down to 0.5 mile (800 meters). Skies begin to clear by sunset; by mid-evening, only cumulus and stratocumulus with bases at 1,500 to 2,500 feet (305 to 610 meters) remain. Visibilities remain good throughout this diurnal cycle; the only restrictions are in rain showers and patchy fog near dawn along rivers and lakes. Fog dissipates rapidly after sunrise. In eastern Peru and Colombia, ceilings and visibilities become typical of the wet season, which see.

WINDS. 5,000-foot (1,500-meter) winds are from 080 to 090° at 10 to 15 knots. Surface winds along the immediate coast are east-northeasterly at 5 to 10 knots. Inland, daylight surface winds are east- northeasterly, becoming easterly towards Manaus; speeds range from 5 to 10 knots. Nights see surface winds decouple from gradient level speeds and become nearly calm. West of Manaus, surface winds are typical of the wet season, which see.

THUNDERSTORMS. Thunderstorm frequency increases dramatically. Very isolated severe thunderstorms occur, primarily along trade wind surges. Although there are no reliable occurrence statistics, fragmentary reports suggest one or two occurrences a month, increasing to four or five a month by the end of December.

PRECIPITATION. Figure 5-128 shows mean November and December rainfall. Note that in the western Northern Amazon Basin, mean monthly rainfall averages nearly as much as during the wet season. There is a dramatic increase in central and eastern portions of the region, especially in the east. The figure gives what is probably the most reliable and complete information available for the interior of South America; it also shows the effects of the Monsoon Trough's passage on precipitation.

TEMPERATURE. Highs range from 68 to 75°F (20 to 23°C) in the Andes foothills to 87 to 91°F (30 to 32°C) in the Amazon Basin and 84 to 86°F (29 to 30°C) along the Atlantic Coast. Lows range from 64 to 72°F (18 to 21°C) in the Andes to 79 to 81°F (25 to 26°C) in the Amazon Basin and 75 to 79°F (23 to 25°C) along the coast.

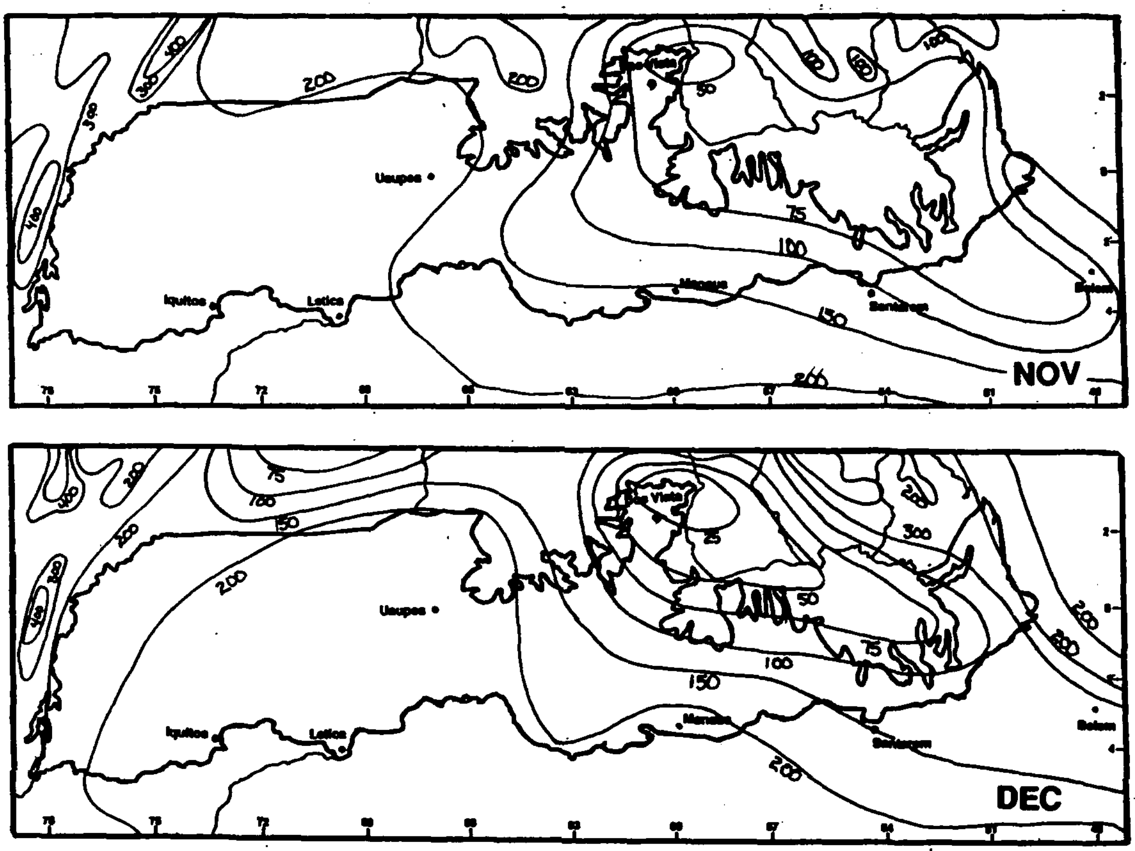


Figure 5-128. Mean Monthly Precipitation: November-December.

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